A Long Term Observation of Gravity During a Conjunction of the Major Planets

A Thesis

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for the Degree, Bachelor of Science

by

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This study deals with six weeks of observations of gravity during the 1982 conjunction of the major planets. Three main objectives formed the basis of this study. The first and foremost was to find what effect, if any, did this alignment of the major planets have on the Earth's gravitational field. The second objective was to obtain an accurate value of the amplitude of the lunar tides which could possibly serve useful in future studies. The last result hoped to be found was a precise measurement of the instrumental drift of the gravimeter, again possibly being of some value in later experiments using this gravimeter.

Changes in the value of gravity with respect to time were observed with a Worden gravimeter kept stationary in a basement room in Mendenhall Laboratory at the Ohio State University in Columbus. Readings were taken from February 18 to March 31, 1982 at approximately four hour intervals during the day and partially into the night. During the eight day period between March 19-26 readings were taken at approximately two hour intervals. A gravity-time curve was plotted indicating a nearly linear drift of the gravimeter. The data was harmonically analyzed for its Fourier components.

Background of the Conjunction

The conjunction of 1982 (some term a "superconjunction") occurs approximately once every 179 years (Gribbin, 1974). Actually, the planets beyond Mars began moving into alignment between 1977 and 1982. In the last few years of this period first Mars, followed by the Earth, and then Venus moved toward their eventual respective positions in the alignment (Gribbin, 1974). Mercury, revolving around the Sun four times in one Earth year, would be both in superopposition, with it on one side of the Sun and the rest of the planets on the other, and in superconjunction, with all the planets on the same side of the Sun four times in 1982 (Gribbin, 1974). The primary superconjunction occurred on March 10, 1982 and is the focus of this study.

In the book, The Jupiter Effect, John R. Gribbin and Stephen H. Plagemann made some predictions as to the effect this superconjunction might have had on the Earth. More specifically, they attempted to link sunspot activity, the tidal influence of the conjunction, and the variations in cosmic rays as a type of combined triggering effect of seismic disturbances "around susceptible regions of the globe." (Gribbin, 1974). They went as far as to predict that a major quake along the San Andreas fault system would be set off by these combined effects (Gribbin, 1974). Time has shown that this proposed disaster has not come to pass. But this is not to say that the alignment of the planets had no effect whatsoever on the Earth as well as the other bodies of the solar system. One of the purposes of this paper is to find if any gravitational variations have occurred because of this conjunction.

To do this we must look at the Earth's gravitational field and how it may vary. Two basic forces determine the Earth's gravitational field and are applied to every point on the surface of the Earth, the resultant of which is a vector directed towards the interior of the Earth (Melchior, 1966). These two forces are the gravitational force due to the attraction of the entire mass of the Earth, and the centrifugal force caused by the Earth's rotation. The length of this vector represents the magnitude of the force of gravity at the point being considered, while the direction of the vector decides the direction of the vertical at that point (Melchior, 1966). The magnitude and direction of gravity are not constants, though, because the Sun and the Moon, each having an attractive force on the point under consideration, vary in their respective distances and directions to that point (Melchior, 1966). As the Earth rotates through the gravitational fields of the Sun and the Moon the gravitational potential of any point on the surface of the Earth will change in a periodic nature due basically to the ellipticities of the Moon and the Earth orbits (Stacey, 1969). These variations in the gravitational potential are dependent upon both latitude and time and can cause periodic variations of the intensity of gravity at the Earth's surface of the order of 2×10^{-6} gals (Melchior, 1966). The marine tides are the most obvious example of these effects but the solid Earth also deforms. This slight yielding of the solid Earth under these tidal forces couses a variation in gravity which is slightly greater than the theoretical calculations for a rigid Earth (Garland, 1965).

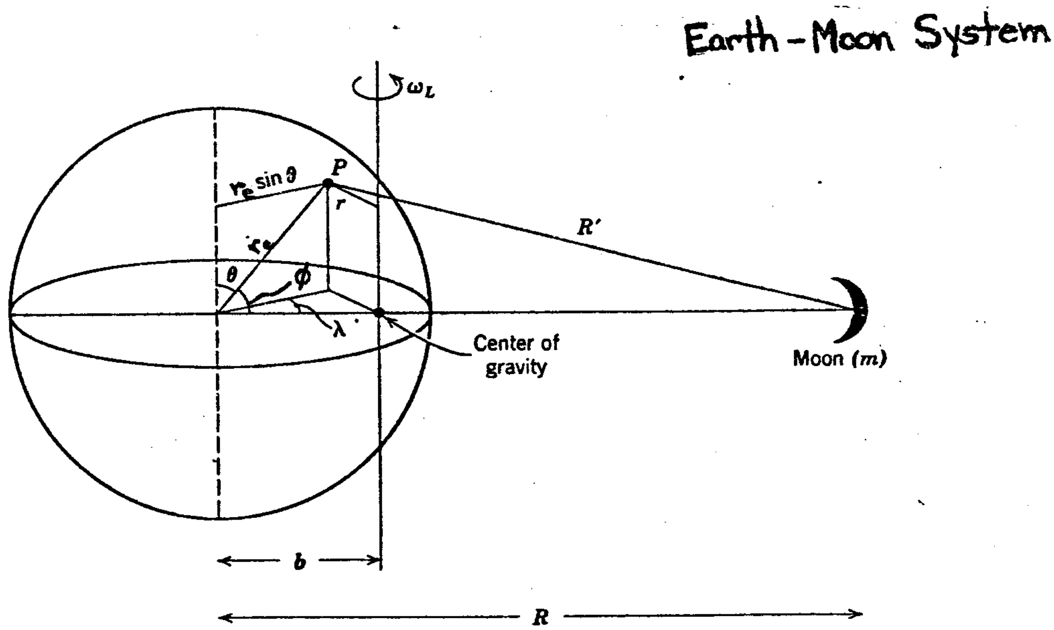
Suppose initially a spherically rigid Earth which is effected only by the Moon. The potential at any point on the Earth's surface would then be due both to the Moon's gravity and rotation, having orbital angular velocity about the axis through the common center of mass (Stacey, 1969):

$$U = \underbrace{\frac{-Gm}{R'}}_{\text{(gravitational potential)}} - \underbrace{\tfrac{1}{2}\omega^2 r^2}_{\text{(rotational potential)}} \tag{1}$$

Here m is the mass of the Moon, R the Earth-Moon distance, r_e the Earth radius, and ϕ the angle between the radius to a point P on the Earth and the Earth-Moon axis. The distance R' can be expressed in terms of r_e, R, and ϕ :

$$(R')^2 = R^2 + r_e^{\,2} - 2r_e\cos\phi$$

figure 1 (Stacey, 1969)



Expanding R' to the second order in r_e/R,

$$(R')^{-1} = R^{-1}\left(1 - \frac{1}{2}\frac{r_e^2}{R^2} + \frac{r_e}{R}\cos\phi + \frac{3}{2}\frac{r^2}{R^2}\cos^2\phi + \ldots\right) \quad (2)$$

The trigonometric relationships

$$\cos\phi = \sin\theta\cos\lambda$$

and

$$\begin{aligned} r^2 &= b^2 + (r_e\sin\theta)^2 - 2b(r_e\sin\theta)\cos \\ &= b^2 + r_e^2\sin^2\theta - 2br_e\sin\phi \end{aligned} \quad (3)$$

and used where b, the location of the Earth-Moon system center of gravity relative to the Earth's spin axis, is given by

$$b = \frac{m}{M+m}R \quad (4)$$

Now from Kepler's third law we can relate the orbital angular velocity and R (Danby, 1962):

$$\begin{aligned} T^2 &= \frac{4\pi^2}{GM}R^2 \\ \frac{4\pi^2}{\omega^2} &= \frac{4\pi^2}{GM}R^2 \\ G(M+m) &= \omega^2 R^3 \end{aligned} \quad (5)$$

Substituting equations 2,3,4, and 5 into 1, rearranging and collecting terms gives

$$U = -\frac{Gm}{R}\left(1 + \frac{1}{2}\frac{m}{M+m}\right) - \frac{Gmr_e^2}{R^3}\left(\frac{3}{2}\cos^2\phi - \frac{1}{2}\right) - \frac{1}{2}\,{}^2 r_e^2\sin^2\theta \quad (6)$$

The first term is the gravitational potential due to the Moon at the center of the Earth with a correction term arising from the mutual rotation (Stacey, 1969). The second term is a second-order zonal harmonic (function of latitude only) and represents a deformation of the equipotential surface to a prolate ellipsoid aligned with the Earth-Moon axis (Stacey, 1969). The tides are caused by the Earth rotating through this potential and so this term is sometimes called the tidal potential:

$$U_2 = -\frac{Gmr_e^2}{2R^3}(3\cos^2\phi - 1) \tag{7}$$

The third term is the rotational potential of the arbitrary point P. It causes an oblate ellipsoidal deformation of the equipotential surface but does not have a tidal effect because it is associated with the axial rotation and thus becomes part of the equitorial bulge of rotation, being vectorially added to the angular momentum (Stacey, 1969).

In our approximation of a rigid Earth, the tidal variation in gravity can now be found from the radial variation in the tidal potential

$$g = -\frac{\partial U_2}{\partial r_e} = \frac{Gmr_e}{R^3}(3\cos^2\phi - 1) \tag{8a}$$

and the circumferential component of the gravity disturbance

$$g = -\frac{1}{r_e}\frac{\partial U_2}{\partial \phi} = -\frac{3}{2}\frac{Gmr_e}{R^3}\sin 2\phi \tag{8b}$$

both being generally latitude dependent (Stacey, 1969).

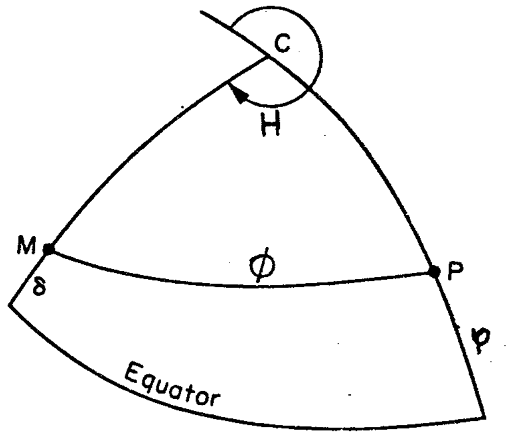
Now that we've seen how the tides are formed, we need to know how the tides caused by the Moon correspond to the tides caused by the Sun so that we can separate them and examine them individually. These different tidal components all originate from the tidal potential (equation 7) and must be extracted from it in some way. The expression for the potential is not convenient, however, since it involves the local coordinate ϕ of the perturbing body being considered. Using the relation

$$\cos\phi = \sin\varphi\sin\delta + \cos\varphi\cos\delta\cos H$$

based on figure 2, where φ is the geocentric latitude of P,

δ the declination, and H the hour angle, we can begin to transform the tidal potential (Melchior, 1966).

figure 2: Quantities required for tidal calculations on a rotating earth. C is the pole of the celestrial sphere, M the moon, P the point on the Earth. (Garland, 1979).



We find consecutively

$$\cos^2\phi = \sin^2\varphi \sin^2\delta + \cos^2\varphi \cos^2\delta \cos^2 H + 2\sin\varphi\cos\varphi\sin\delta\cos\delta\cos H$$

$$\begin{aligned} 3\cos^2\phi - 1 &= 3\sin^2\varphi\sin^2\delta - 1 + 3/2\cos^2\varphi\cos^2\delta(\cos 2H + 1) + 3/2\sin 2\varphi\sin 2\delta\cos H \\ &= 3\sin^2\varphi\sin^2\delta - 1 + 3/2\cos^2\varphi\cos^2\delta + 3/2\cos^2\varphi\cos^2\delta\cos 2H \\ &\quad + 3/2\sin 2\varphi\sin 2\delta\cos H. \end{aligned}$$

Writing the first of these terms as

$$\begin{aligned} 3\sin^2\varphi\sin^2\delta - 1 + 3/2(1 - \sin^2\varphi)(1 - \sin^2\delta) &= 3\sin^2\varphi\sin^2\delta + 3/2\sin^2\varphi\sin^2\delta - 3/2\sin^2\varphi - 3/2\sin^2\delta - 1 + 3/2 \\ &= 3/2\ (3\sin^2\varphi\sin^2\delta - \sin^2\varphi - \sin^2\delta + 1/3) \\ &= 3/2\ (3(\sin^2\varphi - 1/3)(\sin^2\delta - 1/3)) \end{aligned}$$

we arrive at

$$U_2 = G(r)(c/R)^3(\cos^2\varphi\cos^2\delta\cos 2H + \sin 2\varphi\sin 2\delta\cos H + 3(\sin^2\varphi - 1/3)(\sin^2\delta - 1/3)) \qquad (9)$$

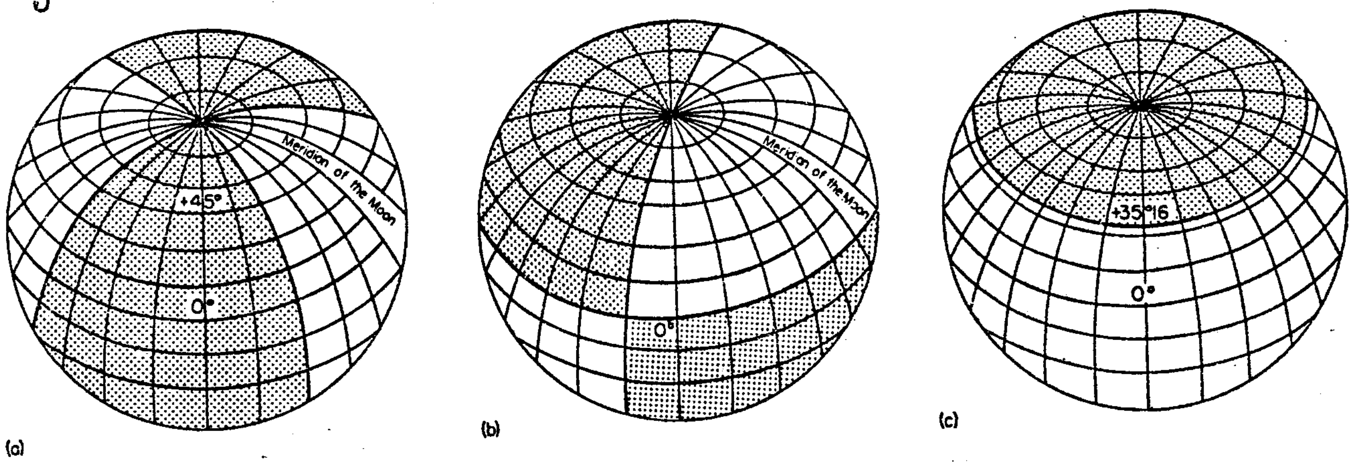
where

$$G(r) = 3/4GM(r_e{}^2/c^3)$$

and we have substituted c equal to the Moon's mean distance (Melchior, 1966).

Laplace was the first to discover this separation of the potential into three terms, each representing a surface spherical harmonic function of the second order and expressed in figure 3 (Melchior, 1966).

figure 3:

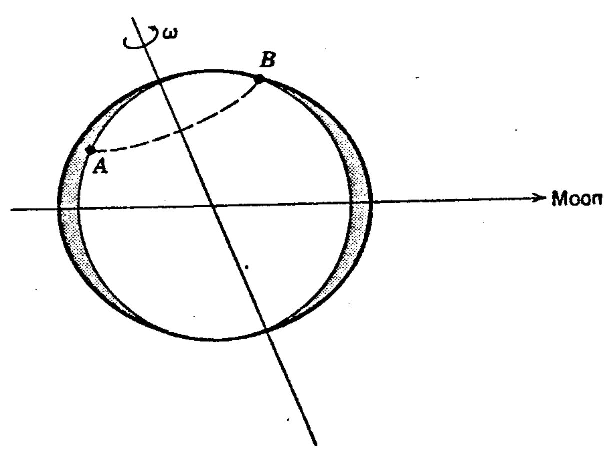


The first term in equation 9 is called the sectorial harmonic because it divides the sphere of figure 3a into four sections by its nodal lines (lines where the function is zero) (Melchior, 1966). The meridians spaced at 45° on either side of the meridian beneath the perturbing body are these nodal lines expressing the regions where the potential is alternately positive and negative: the positive regions are those of high tides ($\varepsilon>0$ where ε is the amplitude of radial deformation or the height of the tide), the negative regions are those of low tides ($\varepsilon<0$) (Melchior, 1966). The period of tides corresponding to the sectorial harmonic is semi-diurnal (½ lunar day) and is expressed in the term cos2H. The amplitudes of such tides reach a maximum at the equator when the disturbing body's declination is zero and are a minimum (zero) at the poles

(Melchior, 1966). With respect to the tidal potential (equation 7) the semi-diurnal tide is the expression of the deformation of the equipotential surface to a prolate ellipsoid (Stacey, 1969).

The second function in equation 9 is called a tesseral harmonic because the regions of the sphere which are divided by the nodal lines change sign with the declination of the body (Melchior, 1966). The nodal lines for this function are the equator and a meridian which is 90° from the meridian of the disturbing body (Melchior, 1966). The period of those tides is diurnal (one lunar day) having its maximum amplitude at latitudes 45°N and 45°S when the declination of the body is maximum but having zero amplitude at the equator and the poles at all times (Melchior, 1966). This diurnal asymmetry to the tides about the equator is called the tidal inequality and is introduced by the rotation of the Earth about an axis inclined to the lunar orbital plane (Stacey, 1969). The tidal inequality is expressed in the figure below.

figure 4 (Stacey, 1969):



A and B represent successive positions of a point on the surface of the Earth at roughly 12 hour intervals. At A the point is close to "high tide", but at B there is hardly any tide. At this stage of the lunar cycle the point sees a predominantly diurnal tide, but the tide becomes semi-diurnal when the Moon is above the equator.

The last function, the zonal harmonic, is dependent only on latitude and is the source of long period tides of the Earth (Garland, 1976). Its nodal lines are at the parallels $+35^\circ 16'$ and $-35^\circ 16'$ (Melchior, 1966). Since it depends only on the square of the sine of the declination of the body, its periods will be 14 days for the Moon and six months for the Sun (Melchior, 1966).

These three different periodic tides (semi-diurnal, diurnal, and long) have been extended to obtain a more precise understanding of Earth tides. In 1921 A.T. Doodson used a purely harmonic treatment of the potential to find the arguements of the components of the tides (Doodson, 1922). The treatment will not be discussed here, but a good summary can be found in Melchior, 1966 . The following table shows the most important components Doodson found, their symbols, and their periods (Garland, 1979).

Symbol	Name	Period (hr)	Amp (μgals)
M_2	Principal lunar	12.42	+90812
S_2	Principal solar	12.00	+42286
N_2	Lunar ellipticity	12.66	+17387
K_2	Lunisolar	11.97	+11506
K_1	Lunisolar	23.93	-53050
O_1	Lunar declination	25.82	+37689
P_1	Solar declination	24.07	+17554

The graph displays the amplitudes, in microgals, of the tidal components as a function of latitide assuming a rigid Earth (Garland, 1979) with the relevant amplitudes for this study occurring at 40 .

figure 4:

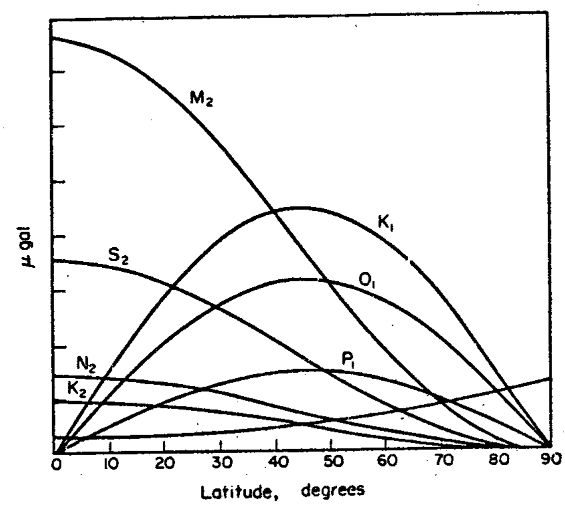


Figure 14.3 Variation with latitude, on a rigid earth, of the principal tidal components.

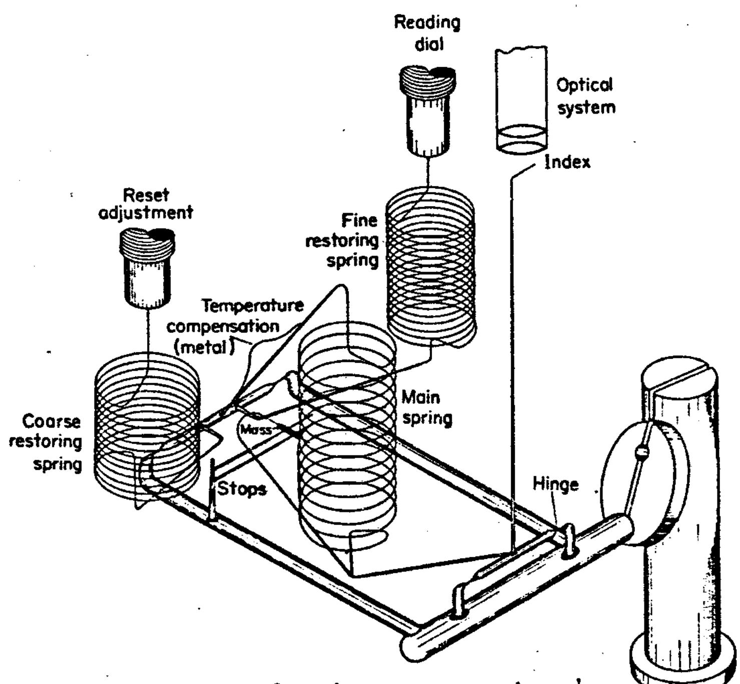
As can be seen from the graph, the Sun and the Moon will have significant effects on both the semi-diurnal tides and diurnal tides at 40° latitude. This overlapping of tidal forces will cause us to look for similar effects on the semi-diurnal and diurnal components of the tides possibly brought on by the alignment of the plants.

Data Collection and Preparation

The data was collected in a basement room of Mendenhall on the Ohio State University campus. The Worden gravimeter was placed on the concrete floor of the basement with specifications: lat., 40°00'N, long., 83°00'45"W, elevation approximately 750 feet above M.S.L., and g., 979.09467cm/sec^2. Three readings were taken for each measurement, one reading corresponding to each of the three hairs in the optical system of the gravimeter. An average reading was obtained from these three and multiplied by the dial constant to acquire the corresponding gravity measurement to the nearest .01 milligals or nearest 10 microgals.

The dial constant is a numerical constant which takes into account the specific temperature of the gravimeter at the time of measurement. The Worden gravimeter is built to reduce temperature changes of the system by mounting it inside a vacuum flash, but differential expansion of a temperature compensation strip keeps the mass in position when temperature does change and this is reflected in the dial constant (Garland, 1965).

figure 5:



working parts of Worden gravimeter

Each measurement was obtained in the following manor:

1) the gravimeter was leveled.
2) the dial was adjusted so that the lighted beam of the system fell in line with the right hair of the system.
3) the reading was taken from the dial and circled to mark

it as the first of three reading.

4) the dial was adjusted so that the lighted beam fell along the middle hair of the optical system and another reading was recorded.

5) the time, temperature, and corresponding dial constant were recorded.

6) the lighted beam was then moved by adjusting the dial to the left hair and the last reading was recorded.

7) for the next measurement the exact procedure was repeated except that the lighted beam fell on the left hair first and the reading was recorded.

8) alternation of the first reading between left and right hairs was repeated throughout the collection of data with each first reading circled so to average out any inequalities in backlash of the dial mechanism.

9) a total of 222 observations were recorded.

Once the data had been collected, a gravity-time curve was constructed. Because of the lack of measurements roughly between the hours of 12:00 a.m. and 6:00 a.m. there were discontinuities in this curve. Since equal interval values throughout each entire day were needed to harmonically analyze the data, these discontinuities had to be accounted for in some way. A linear drift curve was assumed and the best fit straight line was drawn through the gravity-time curve. The drift is mainly the result of creep in the springs of the gravimeter and under ideal static conditions is unidirectional (Telford, Geldart, Sheriff, Keys, 1976). Because of the relatively short duration of this study (42 days) and the general static conditions, a linear relationship is expected, and observed.

Data was read off the gravity-time curve in three hour intervals to be harmonically analyzed. When values were needed from parts of the graph where discontinuities occurred, values were taken from the linear drift curve, with the assumption that when the data was harmonically analyzed the discontinuous regions would contribute principally to the zeroeth harmonic or time-average component of the Fourier Series.

Harmonic Analysis-The Fourier Series

The periodic character of the Earth's gravitational field caused by the cyclic nature of the Moon's rotation about the Earth and the Earth's rotation about the Sun allows us to harmonically analyze the data. The problem here is that we do not know what specific periodic function will represent this collection of data accurately. A very powerful and frequently used mathematical technique to find such a function is called Fourier Analysis. Fourier's Theorem states that any periodic function can be expressed by a trigonometric series of the form

$$f(t) = \tfrac{1}{2}a_o + \sum_{n=1}^{\infty} (a_n \cos nt + D_n \sin nt) \qquad (10)$$

(Sokolmikoff and Redheffer, 1958).

Here I have used t as the dependent variable representing time, as is the case in this study.

In this expansion, the various terms are called the harmonics of f(t), the cosine terms being the "cosine harmonics" and the sine terms, the "sine harmonics". For example $a_1 \cos t$ is the first cosine harmonic and $b_2 \sin 2t$ is the second sine harmonic. The two n^{th} harmonic terms $a_n \cos nt + b_n \sin nt$ can be combined in the form

$$(a_n^2 + b_n^2)^{1/2} \cos(nt - \phi)$$

where

$$\tan \phi = \frac{b_n}{a_n}$$

This expression is the resultant or complete harmonic; $(a_n^2+b_n^2)^{1/2}$ being its amplitude and ϕ its initial phase (Noltimier, personal communication), the amplitude being the principal component we are searching for in this study. The "first harmonic" is often called instead, the fundamental harmonic with the a's and b's being the Fourier coefficients of the harmonics representing the amplitudes of their respective corresponding trigonometric components.

We can expect and see from the gravity-time curve the periodic nature of the data superimposed on some linearly increasing element, this element assumed and found to be caused by the drift of the gravimeter. So we can now express the data as a combination of cosine and sine terms. As will be clarified later, what we really want to derive from this collection of data is not the specific periodic function that accurately represents the data, but the coefficients of the sine and cosine terms which make up the Fourier Series.

To do so we first assume that f(t) is known on $(0, 2\pi)$ and that the series is uniformly convergent so that it can be integrated term by term from 0 to 2π.

Since

$$\int_0^{2\pi} \cos nt\,dt = \int_0^{2\pi} \sin nt\,dt = 0 \text{ for } n=1,2,3,\ldots$$

the calculation results in

$$\int_0^{2\pi} f(t)dt = a_o\pi \qquad \text{or} \qquad a_o = \frac{1}{\pi}\int_0^{2\pi} f(t)dt \tag{11}$$

To find the coefficient a_n we multiply equation (10) by cosnt yielding

$$f(t)\cos nt = \tfrac{1}{2}a_o \cos nt + \ldots + \tfrac{1}{2}a_n \cos^2 nt + \ldots \tag{12}$$

where the terms not written involve products of the form sinmtcosnt or of the form cosmtcosnt with $m \neq n$. For integral values of m and n, these products can be shown to be equal to zero or π as follows:

$$\int_0^{2\pi} \cos nt \cos mt\,dt = \int_0^{2\pi} \frac{(e^{int} + e^{-int})}{2}\,\frac{(e^{imt} + e^{-imt})}{2}\,dt$$

where we have used $\cos z = (e^{iz} + e^{-iz})/2$.

Then

$$4\int_0^{2\pi} \cos nt \cos mt\,dt = \int_0^{2\pi} (e^{i(m+n)t} + e^{i(m-n)t} + e^{i(n-m)t} + e^{-i(m+n)t})dt \tag{13}$$

Each term on the R.H.S. of equation 13 is in the form e^{iht} with h an integer, giving zero unless m=n. If m=n the two middle terms give 2, so that the integral is 4 , or correspondingly,

$$\int_0^{2\pi} \cos nt \cos mt\,dt = \begin{cases} 0 \text{ if } m \neq \pm n \\ \pi \text{ if } m = n \end{cases}$$

It can be similarly verified using the relationship

$$\sin z = (e^{iz} - e^{-iz})/2$$

that

$$\int_0^{2\pi} \sin mt \cos nt\,dt = 0 \quad \text{in general.}$$

Integration of equation 12 then yields

$$\int_0^{2\pi} f(t)\cos nt\,dt = a_n \int_0^{2\pi} \cos^2 nt\,dt$$

$$= a_n/2 \int_0^{2\pi} (1 + \cos 2nt)dt$$

$$= a_n \pi$$

Therefore:

$$a_n = \frac{1}{\pi} \int_0^{2\pi} f(t)\cos nt\,dt \tag{14a}$$

Similarly multiplying equation (10) by sinnt and integration yields

$$b_n = 1/\pi \int_0^{2\pi} f(t)\sin nt\,dt \tag{14b}$$

The formulas (14a) and (14b) are called the Euler-Fourier formulas and are, along with equation (11), the coefficients we are looking for.

Again, we are confronted with the problem of not knowing the periodic function. In such cases it is necessary to modify the formulae for the coefficients so that a numerical method can be used for their evaluation. (Calus and Fairley, 1970).

In general, the radius of the periodically changing variable, gravity in our case, is measured at n equidistant values of θ covering a period of 2π (Calus and Fairley, 1970). The coefficients in the Fourier Series for $g=f(\theta)$ are found in the following manor:

$a_o = 1/\pi \int_0^{2\pi} f(\theta)dt$ = 2 X mean value of $f(\theta)$ over one period

$a_n = 1/\pi \int_0^{2\pi} f(\theta)\cos n\theta d\theta$ = 2 X mean value of $f(\theta)\cos n\theta$ over one period

$b_n = 1/\pi \int_0^{2\pi} f(\theta)\sin n\theta d\theta$ = 2 X mean value of $f(\theta)\sin n\theta$ over one period.

Since $f(\theta)$ is not known, an approximation to the mean value of $f(\theta)$ is derived taking the mean of the values of g at the respective θ values (Calus and Fairley, 1970).

$$\text{i.e. } \sum g/n$$

Similarly the mean value of $f(\theta)\cos n\theta$ is taken to be

$$\sum g\cos n\theta/n$$

and that of $f(\theta)\sin n\theta$ as

$$\sum g\sin n\theta/n$$

So we arrive at the respective coefficients,

$a_o = 2\sum g/n$ $\qquad$ $a_1 = 2\sum g\cos\theta/n$ $\qquad$ $b_1 = 2\sum g\sin n\theta/\theta$

The accuracy of this approximation method decreases with increasing harmonic terms, being fairly reliable to the first (n/2 - 1) harmonics, n being the number of intervals (Calus and Fairley, 1970). Improving the accuracy corresponds to decreasing the interval between values (i.e. increasing the number of measurements) which is obvious when you realize you are basically replacing integration by summation.

The actual mathematical computations were carried out on the Fortran G1 compiler of the computer system on the Ohio State University campus. The collected data was tabulated and digitized at three hour intervals and harmonically analyzed based on five different periodic ranges: 1) 24 hour periods. 2) 12 hour periods from midnight to noon and then noon to midnight. 3) 12 hour periods from 6:00 a.m. to 6:00 p.m. 4) 48 hour periods and 5) weekly periods.

The computer program used was the IBM subroutine FORIT which produces the Fourier coefficients of a tabulated function. The resultant n^{th} harmonic (amplitude and phase) was incorporated into the program so as to be able to detect the complete effect this alignment of the planets had and not just the individual sine and cosine components.

An example of the 24 hour period program follows:

```
11                EXEC FTGICG, SYSLIB = SINGLE
11 FORT.SYSIN  DD  *
      DIMENSION A(5), B(5), FNT(9), AMP(5), PHAS(5)
C     A IS THE COSINE COEFFICIENTS TO BE CALCULATED
C     B IS THE SINE COEFFICIENTS TO BE CALCULATED
C     FNT IS THE DATA TO BE ANALYZED
C     AMP IS THE RESULTANT AMPLITUDE EQUAL TO √(A² + B²)
C     PHAS IS THE PHASE ANGLE EQUAL TO TAN⁻¹B/A
      N = 4
      M = 4
C     N SUCH THAT THERE ARE 2N + 1 TABULATED DATA POINTS:
         2K /(2N+1), K=0,1,2,...,2N
C     M IS THE DESIRED ORDER OF THE FOURIER COEFFICIENTS
         WHERE 0≤ M≤ N
C     SET PARAMETERS AND READ IN DATA
      K = M + 1
      L = 2N + 1
      READ (5,5) (FNT(1), I=1, 5)
      READ (5,6) (FNT(1), I=6,L)
```

```
C     APPLY DATA TO SUBROUTINE
      CALL FORIT (FNT, N, M, A, B, IER)
C     CALCULATE THE AMPLITUDE AND PHASE ANGLE OF EACH
C     HARMONIC
      DO 10 I = 1,K
         AMP(I) = SQRT((A(I)**2) + (B(I)**2))
         PHAS(I) = ATAN(B(I)/A(I))
10    CONTINUE
C     PRINT OUT THE COSINE, SINE AND RESULTANT AMPLITUDES
         AS WELL AS THEIR PHASE RELATIONSHIP
      WRITE (6,20)
      DO 100 I=1,K
        WRITE (6,30) A(I), B(I), AMP(I), PHAS(I)
100   CONTINUE
C     PRINT OUT TABULATED DATA AS A CHECK AND REFERENCE
      WRITE (6,35)
      DO 200 I=1,L
         WRITE (6,40) FNT(I)
200   CONTINUE
5     FORMAT (F6.3, 10X, F6.3, 10X, F6.3,10X, F6.3, 10X, F6.3, 10X)
6     FORMAT (F6.3, 14X, F6.3, 14X, F6.3, 14X, F6.3, 14X)
20    FORMAT ( ' ', 1X, SINE TRANSFORM', 2X,'COSINE TRANSFORM.',2X
         'AMPLITUDE', 5X, 'PHASE ANGLE')
30    FORMAT (' ', 1X, F12.5, 6X, F12.5, 6X, F12.5, 9X,F12.5)
35    FORMAT (' ', 1111, 20X, 'DATA TRANSFORMED', 11)
40    FORMAT (' ', 24X, F7.3, 1)
      STOP
      END
```

```
C    CODE FOR ACCESS TO FORIT SUBROUTINE
11 GO.SYSLIB _ DD _ DISP= SHR
11             DD _ DSN = SYS2.FORTSSP, DISP= SHR
11 GO.SYSIN    DD *
     DATA
1*
11
C    SUBROUTINE FORIT
C
C    PURPOSE
C        FOURIER ANALYSIS OF A PERIODICALLY TABULATED FUNCTION.
C        COMPUTES THE COEFFICIENTS OF THE DESIRED NUMBER OF
C        TERMS IN THE FOURIER SERIES F(X) = A(O)*SUM(A(K)COSKX+B(X)
C        SIN KX) WHERE K = 1,2,...,M TO APPROXIMATE A
C        GIVEN SET OF PERIODICALLY TABULATED VALUES
C        OF A FUNCTION
C
C    USAGE
C        CALL FORIT(FNT, M, N, A, B, IER)
C
C    DESCRIPTION OF PARAMETERS
C        FNT-VECTOR OF TABULATED FUNCTION VALUES OF LENGTH 2N+1
C        N  -DEFINES THE INTERVAL SUCH THAT 2N+1 POINTS ARE TAKEN
C            OVER THE INTERVAL (0, 2PI).  THE SPACING IS THUS 2PI/2N+1
C        M  -MAXIMUM ORDER OF HARMONICS TO BE FITTED
C        A  -RESULTANT VECTOR OF FOURIER COSINE COEFFICIENTS OF
C            LENGTH M+1
```

```
C           A SUB 0, A SUB 1..... A SUB M
C        B -RESULTANT VECTOR OF FOURIER SINE COEFFICIENTS OF
C           LENGTH M+1
C           B SUB 0, B SUB 1..... B SUB M
C        IER-RESULTANT ERROR CODE WHERE
C           IER=0 NO ERROR
C           IER=1 N NOT GREATER OR EQUAL TO M
C           IER=2 M LESS THAN 0
C
C     REMARKS
C        M MUST BE GREATER THAN OR EQUAL TO ZERO
C        N MUST BE GREATER THAN OR EQUAL TO M
C        THE FIRST ELEMENT OF VECTOR B IS ZERO IN ALL CASES
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        NONE
C
C     METHOD
C        USES RECURSIVE TECNIQUE DESCRIBED IN A. RALSTON, H. WILF,
C        "MATHEMATICAL METHODS FOR DIGITAL COMPUTERS", JOHN WILEY
C        AND SONS, NEW YORK, 1960, CHAPTER 24, THE METHOD OF INDEXING
C        THROUGH THE PROCEDURE HAS BEEN MODIFIED TO SIMPLIFY THE
C        COMPUTATION.
C
C     ...................................................................
C     SUBROUTINE FORIT(FNT, N, M, A, B, IER)
      DIMENSION A(1), B(1), FNT(1)
C
```

```
C         CHECK FOR PARAMETER ERRORS
C
      IER=0
   20 IF(M) 30,40,40
   30 IER=2
      RETURN
C
C         COMPUTE AND PRESET CONSTANTS
C
   60 AN=N
      COEF=2.0/(2.0 * AN+1.0)
      CONST=3.141593 * COEF
      S1=SIN(CONST)
      C1=COS(CONST)
      C=1.0
      S=0.0
      J=1
      FNTZ=FNT(1)
   70 U2=0.0
      U1=0.0
      Z=2*N+1
C
C         FORM FOURIER COEFFICIENTS RECURSIVELY
C
   75 U0=FNT(I)+2.0*C*U1-U2
      U2=U1
      U1=U0
```

```
      I=I-1
      IF(I-1) 80,80,75
   80 A(J)=COEF*(FNTZ+C*U1-U2)
      B(J)=COEF *S*U1
      1=(J-(M+1)) 90, 100, 100
   90 Q=C1*C-S1*S
      S=C1*S+S1*C
      C=Q
      J=J+1
      GO TO 70
  100 A(1)=A(1)*0.5
      RETURN
      END
```

The programs for the other periods vary only in that the magnitude of variables pertaining to input data are increased or decreased according to the length of the period and not in the general structure, so they will not be documented here.

Observed Effects of the Conjunction

Once the resultant amplitudes were computed for the five periods studied, they were plotted against time using the Versatec Plotting System. These gravity-time curves represent the variation of amplitude of specific tidal components (harmonics) during this 42 day study. The principal tidal components examined were the diurnal and semi-diurnal components since these represent the major tidal effects on the solid Earth. It is unlikely that the conjunction could have had a direct measureable effect on the gravitational field of the Earth when considering the precision of the Worden gravimeter (.01 mgal). But the alignment could have caused a perturbation to the Moon's orbit changing the Moon's declination slightly and thus indirectly effecting the Earth tides. This indirect effect on the Earth tides was hoped to be seen in the principal declination dependent tidal components.

In comparing the Versatec gravity-time graphs, a conjunction effect was hoped to be observed through similar variations of the semi-diurnal and diurnal components the week preceding, of, and following the conjunction. There are obvious similarities to the trends of the two tidal components and the parallelism of these trends is sketched in on the graphs (pp.33-44), but irregularities around the time of the conjunction (the 21st day on the graphs) can not be distinguished. The irregularities might be present, but because of the short duration of the study (42 days), compared to the lunar cycle (approximately 28 days), a complete repetition of the lunar cycle is not present, and thus any irregularities in the gravitational amplitudes of the declinational tidal components can not be observed.

Even if a more complete record (3 months for example) of the gravitational variation was obtained, there could be other effects which could dominate the conjunction's effect. The chart in figure 5 shows that the principal diurnal components dependent on the declination of the Moon are K_1 and O_1. Of the semi-diurnal components K_2 is the only principal harmonic dependent on the Moon's declination. It seems that an effect could be seen if these components were separated and isolated, but there are factors which complicate the picture. The sun induces important perturbations in the lunar orbit, causing the Moon's declination to vary with a period of 27.321 mean solar days and thus forming natural waves of evection and variation in K_2 (Melchior,1966). This solar perturbation of the Moon could have a masking effect when looking for the effect of the conjunction. In addition, K_2 is a solar declinational component combined with a lunar declinational component and it would be impossible to distinguish the two without more sophisticated filtering techniques and a much longer data collection period (12 months).

Similarly, the diurnal lunisolar component (K_1) has both a lunar and solar origin and it is impossible to separate the two with only 42 days of data. Also, the solar declination (S_1) is so similar in period to the lunisolar and lunar declination components that there could be a masking effect here also.

In conclusion, a tidal effect of the conjunction of the planets can not be observed. The length of gravity observations was much too short and should possibly be lengthened to up to 12 months with measurements taken every hour for greater precision. A more accurate gravimeter combined with more in depth filtering techniques could possibly serve to uncover and separate any of the dominating and masking effects of other tidal components.

Lunar Amplitude

The second objective hoped to be gained from this study was a value for the average amplitude of the principal lunar component of the Earth tides. The principal lunar component (M_2) has a period of 12.42 hours. The gravity-time curve had to be broken up into two and one half hour intervals instead of three hour intervals to obtain an approximate principal lunar period of 12.50 hours because of the length of this period. The gravity readings taken from the curve with this interval resulted in an odd number of readings per period making it necessary to use the IMSL subroutine FFTSC to harmonically analyze the data instead of the IBM subroutine FORIT which requires an even number of readings per period. Both subroutines essentially analyze the data in the same fashion so no accuracy is lost in this transition.

The graph of the amplitudes of the principal lunar component shows the general trend of the other tidal components in that there is commonly seen a roughly sinusoidal trend extending through one and a half periods of oscillation. The average principal lunar amplitude was obtained by finding the mean value of the lunar amplitudes, the value found being 0.705 mgals, and is shown on the graph as a horizontal line extending through the graph. This value lies well within the range of theoretical values for the lunar amplitude (Melchior,1966).

Instrumental Drift

The last objective of this study was to find a value for the instrumental drift of the Worden gravimeter. As discussed previously, there were discontinuities in the gravity-time curve which were accounted for by assuming a linear drift of the gravimeter. This was justified because of the relatively short duration of the study and the general static conditions throughout the study. Also, a general linear trend can be seen from the gravity-time curve even when not considering the discontinuous regions.

To obtain measurements of the instrumental drift of the gravimeter the time dependent zeroeth harmonic, or time-average component of the Fourier Series, was tabulated and plotted versus time with the Versatec Plotting System for several of the periods analyzed. For every period analyzed a linearly increasing trend was observed. The instrumental drift was calculated for each period analyzed, along with the corresponding mean standard variation of this linear regression line. The instrumental drift was just the slope of the zeroeth harmonic graph for the respective period. The standard deviation was calculated for each point of a graph using the formula

$$S_x = \left[\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{(N-1)}\right]^{1/2}$$

where S_x is the standard deviation, X is the corresponding gravity measurements for a specific period, and N is the total number of measurements in that period (Noltimier and Cherry,1982). Once a standard deviation was obtained for each point, the mean standard deviation was found by averaging these values.

The standard deviation reveals that there were fluctuations superimposed on the drift of the gravimeter which averaged a 39% difference from the linear trend of this drift component and were predominantly caused by the principal tidal components.

The following table is a list of instrumental drift values for the corresponding periods along with the mean standard deviations and the adjustment of these values with respect to a 24 hour period.

Period (hrs)	Drift(mgals/period)	Adjusted Drift	S_x (mgals)
24	0.487	0.487	0.187
12	0.242	0.479	0.096
12 (6-6)	0.240	0.480	0.088
48 (n-n)	0.939	0.470	0.330
48 (m-m)	0.942	0.471	0.324
168 (n-n)	2.885	0.412	0.939
168 (m-m)	2.787	0.398	1.142

(6-6) = data grouped & analyzed between 6:00 a.m. & 6:00p.m.
(n-n) = data grouped & analyzed between noon & following noon
(m-m) = data grouped & analyzed from midnight to midnight

A measurement of the degree of linearity of the drift of the gravimeter was obtained by superimposing on the gravity-time curve the best fit polynomial of degree one and correlating the drift of the curve with this polynomial. The method followed was based on the discussion given in Data Reduction and Error Analysis for the Physical Sciences (Bevington,1969). A copy of the program written to apply this technique can be found in the appendices.

The results of the analysis reveal a near perfect linear trend shown in the correlation coefficient of 0.977 and having a variability of 0.00007.

Conclusions

1. No conjunction effect on the solid Earth tides could be observed. The relative shortness of the gravity observation period compared to the lunar cycle and alignment period of the planets, the possible masking effects of the overlapping tidal constituents, and possibly the lack of a more precise gravimeter could have individually or unitely caused the tidal effect of the super-conjunction to be obscured.

2. The principal lunar tidal constituent (M_2) was found to have a relative value of 0.705 mgals.

3. The drift of the Worden gravimeter used in this study was found to be 0.487 milligals per day. A linear trend of the drift was observed having an average linear correlation coefficient of 0.977 with a variability of 0.00007.

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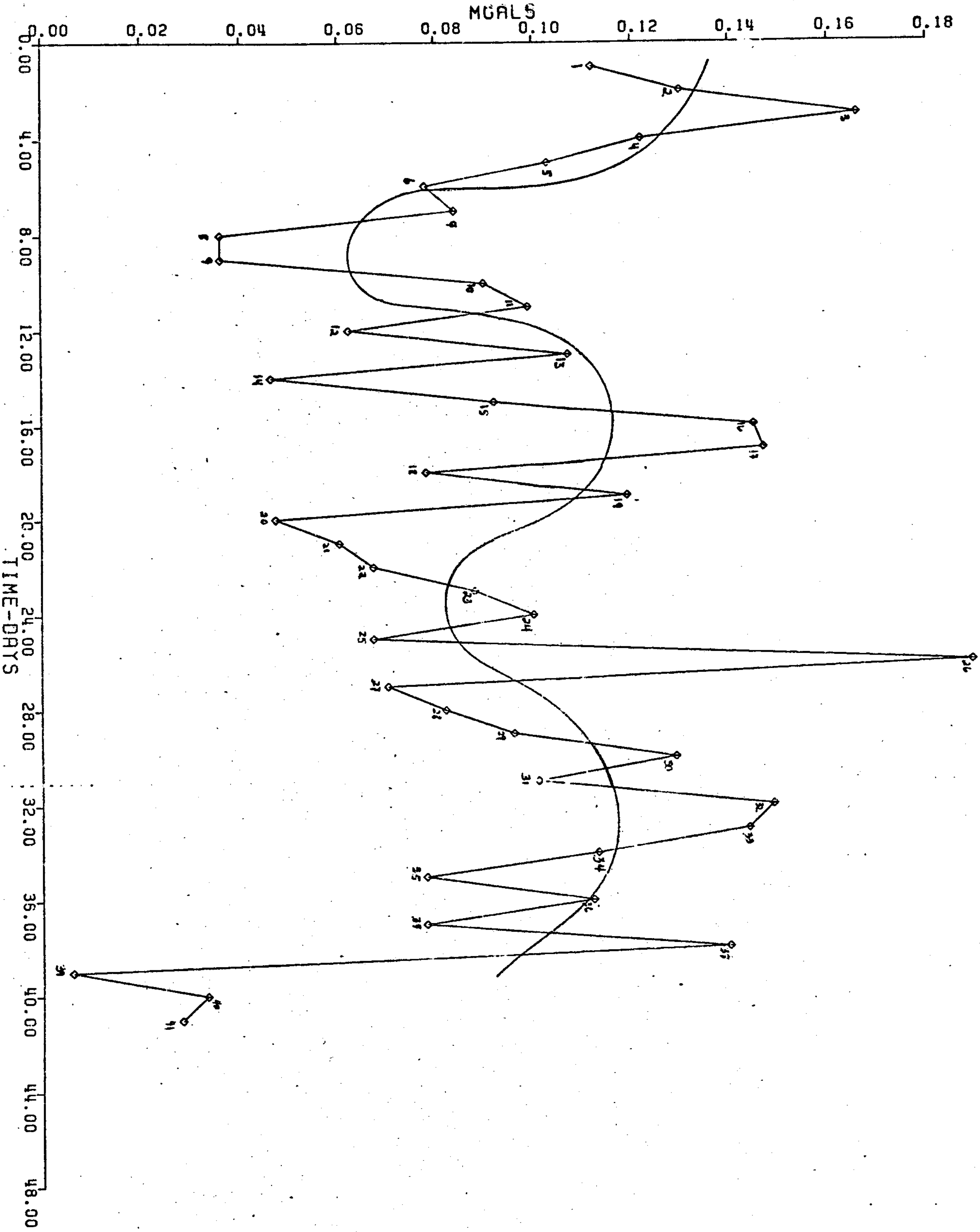
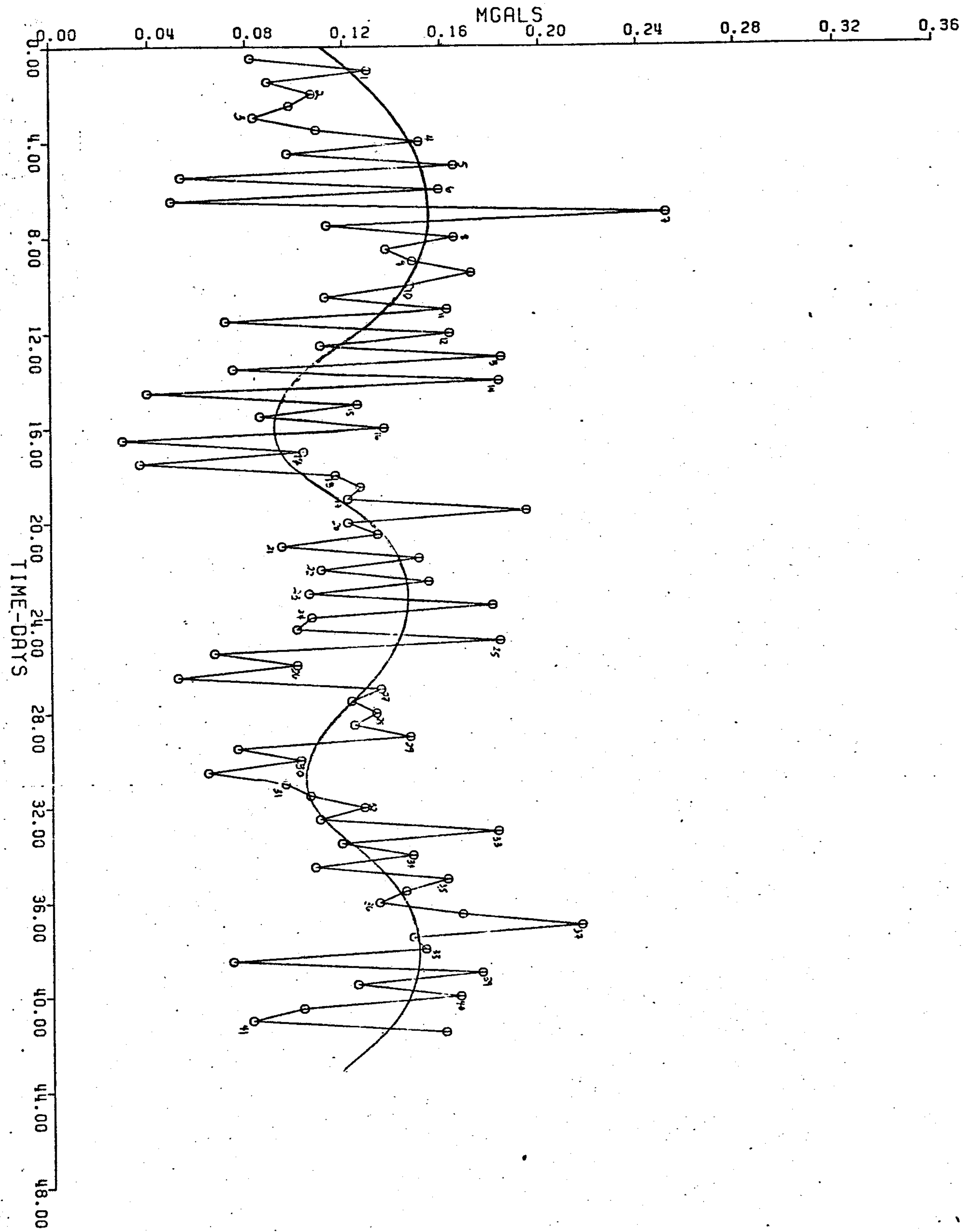
APPENDIX I:

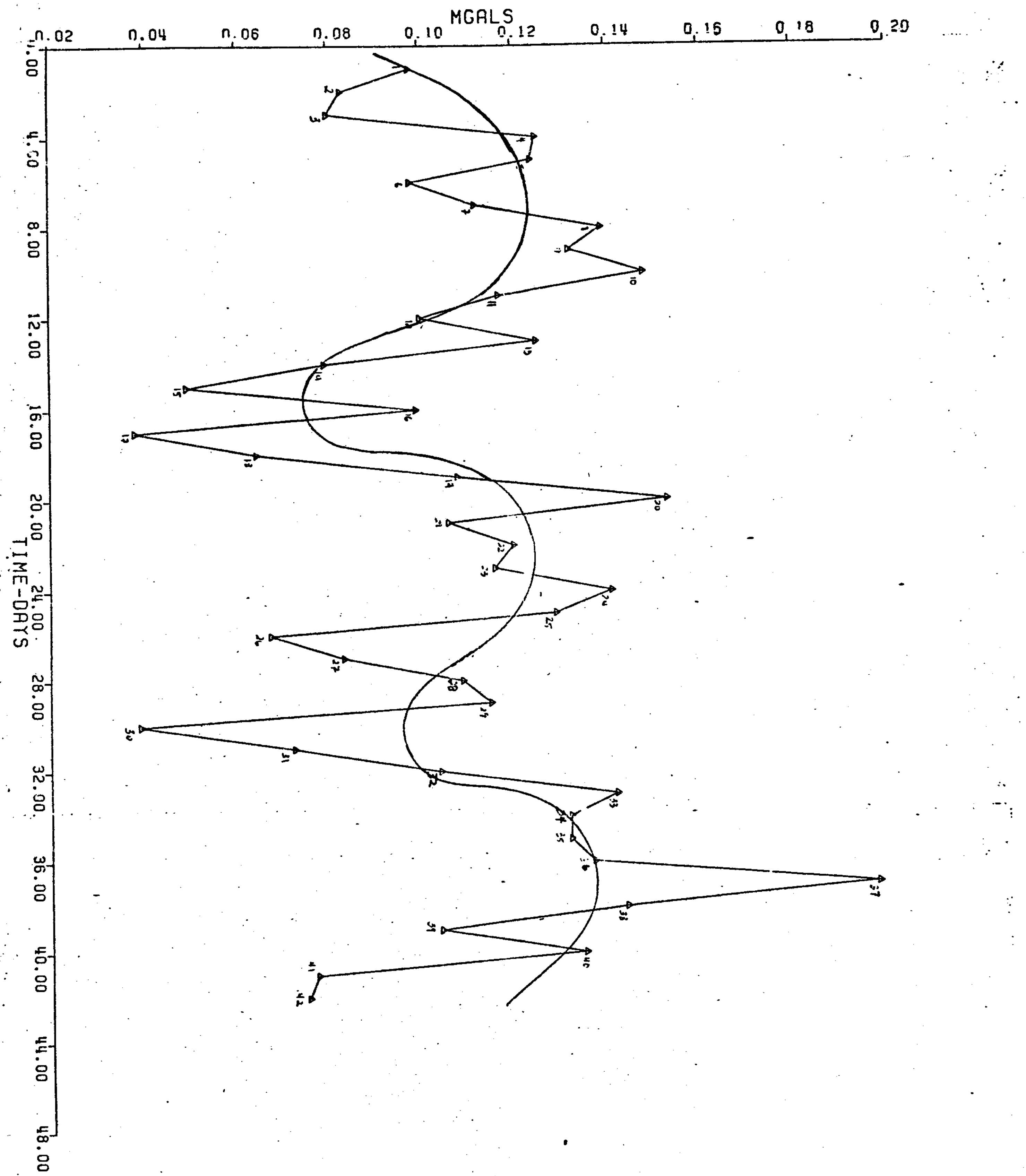
GRAPHS OF HARMONIC COMPONENTS



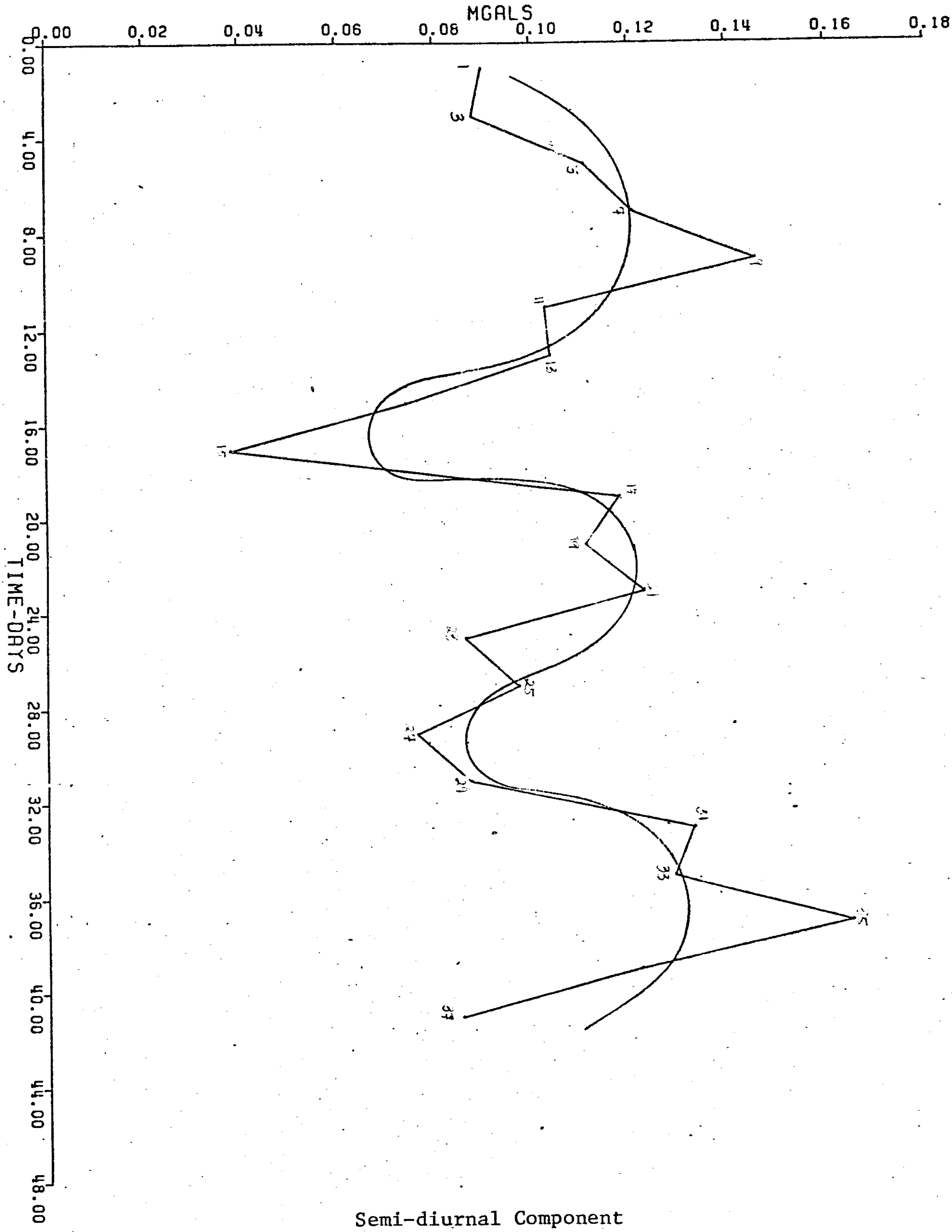
Semi-diurnal Component
12 hour period - first harmonic
data grouped & analyzed between 6:00 a.m. and 6:00 p.m.
smooth curve reflects general trend of data



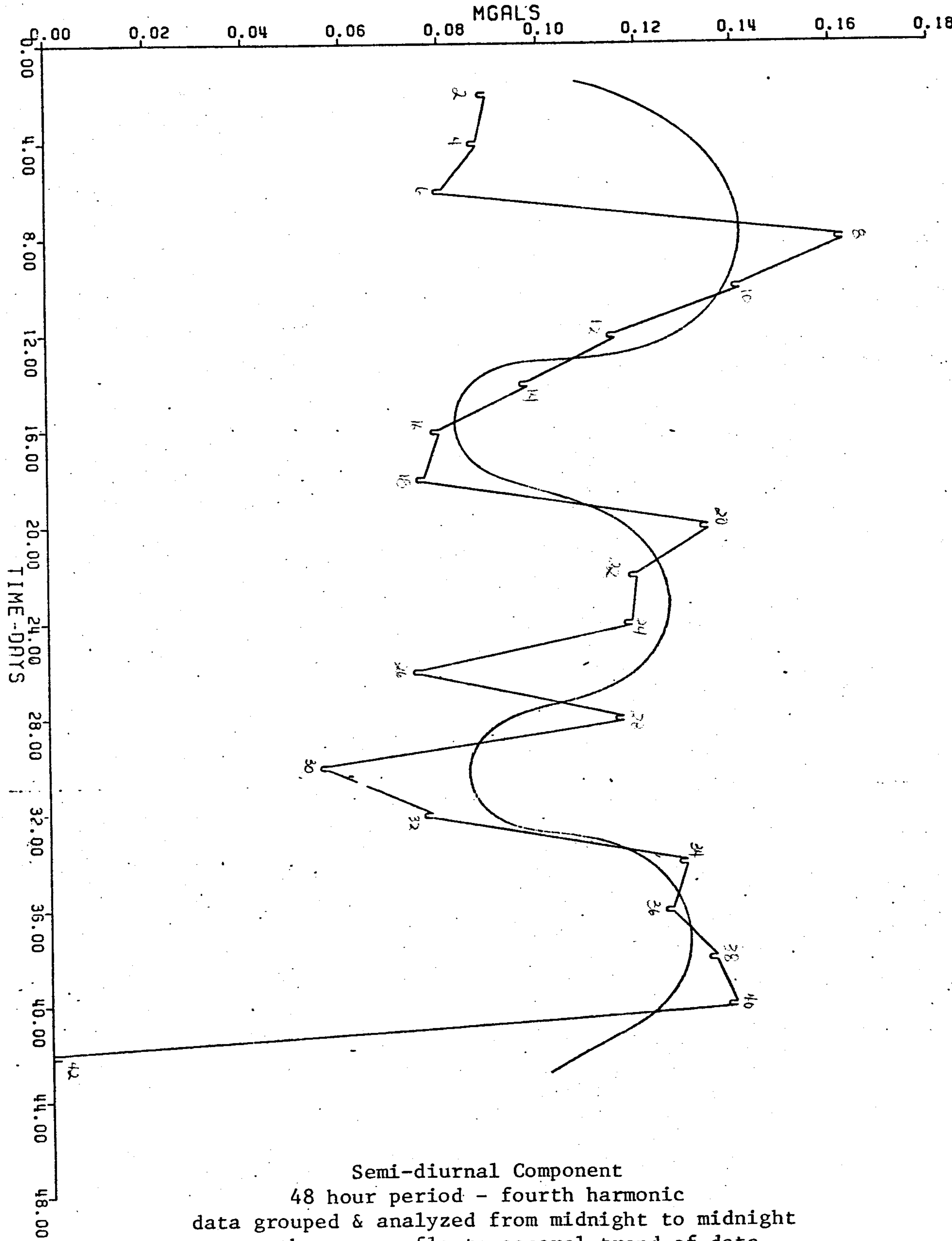
Semi-diurnal Component
12 hour period - first harmonic
data grouped & analyzed between noon and following noon
smooth curve reflects general trend of data



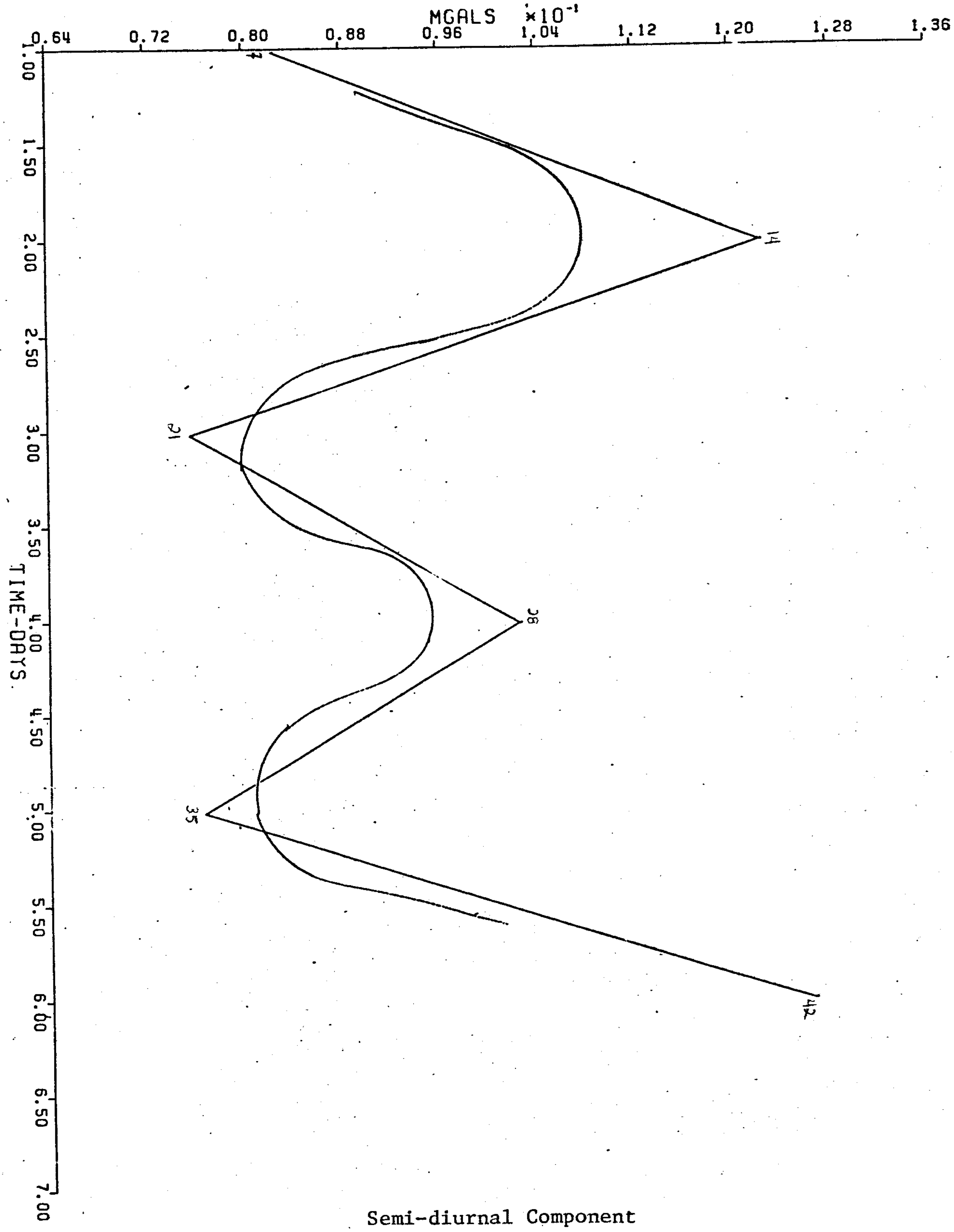
Semi-diurnal Component
24 hour period - second harmonic
smooth curve reflects general trend of data



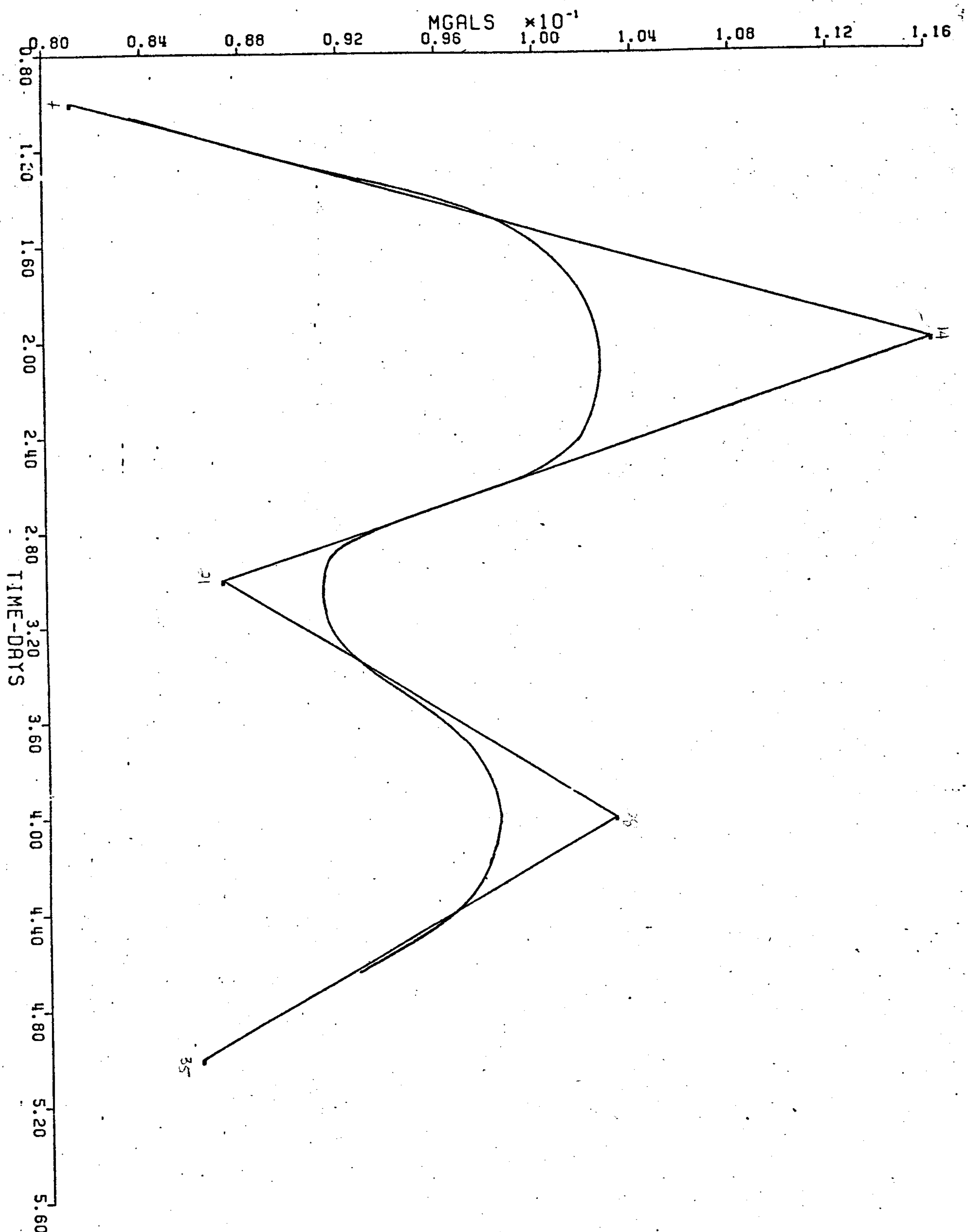
Semi-diurnal Component
48 hour period - fourth harmonic
data grouped & analyzed between noon and following noon
smooth curve reflects general trend of data



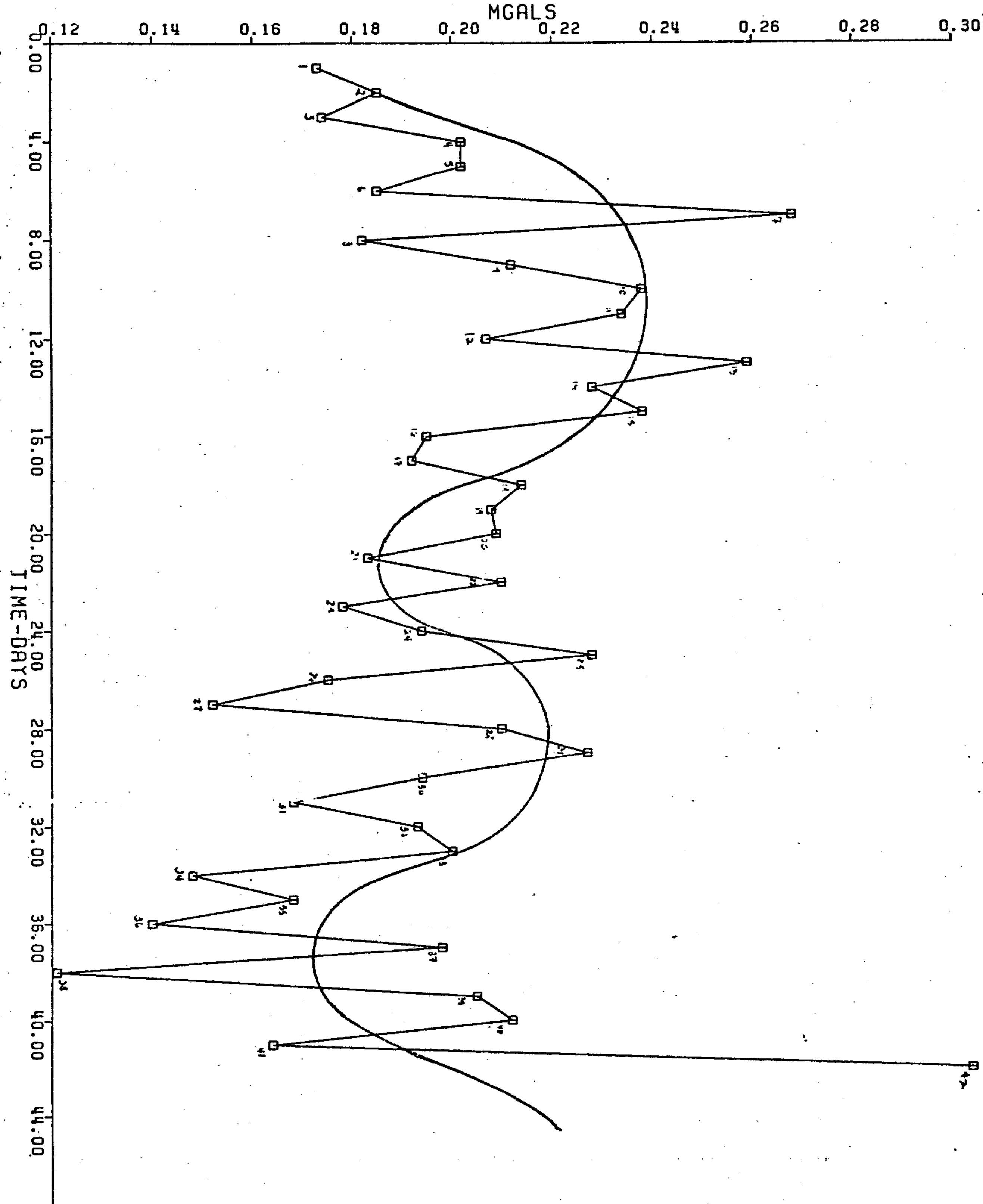
Semi-diurnal Component
48 hour period - fourth harmonic
data grouped & analyzed from midnight to midnight
smooth curve reflects general trend of data



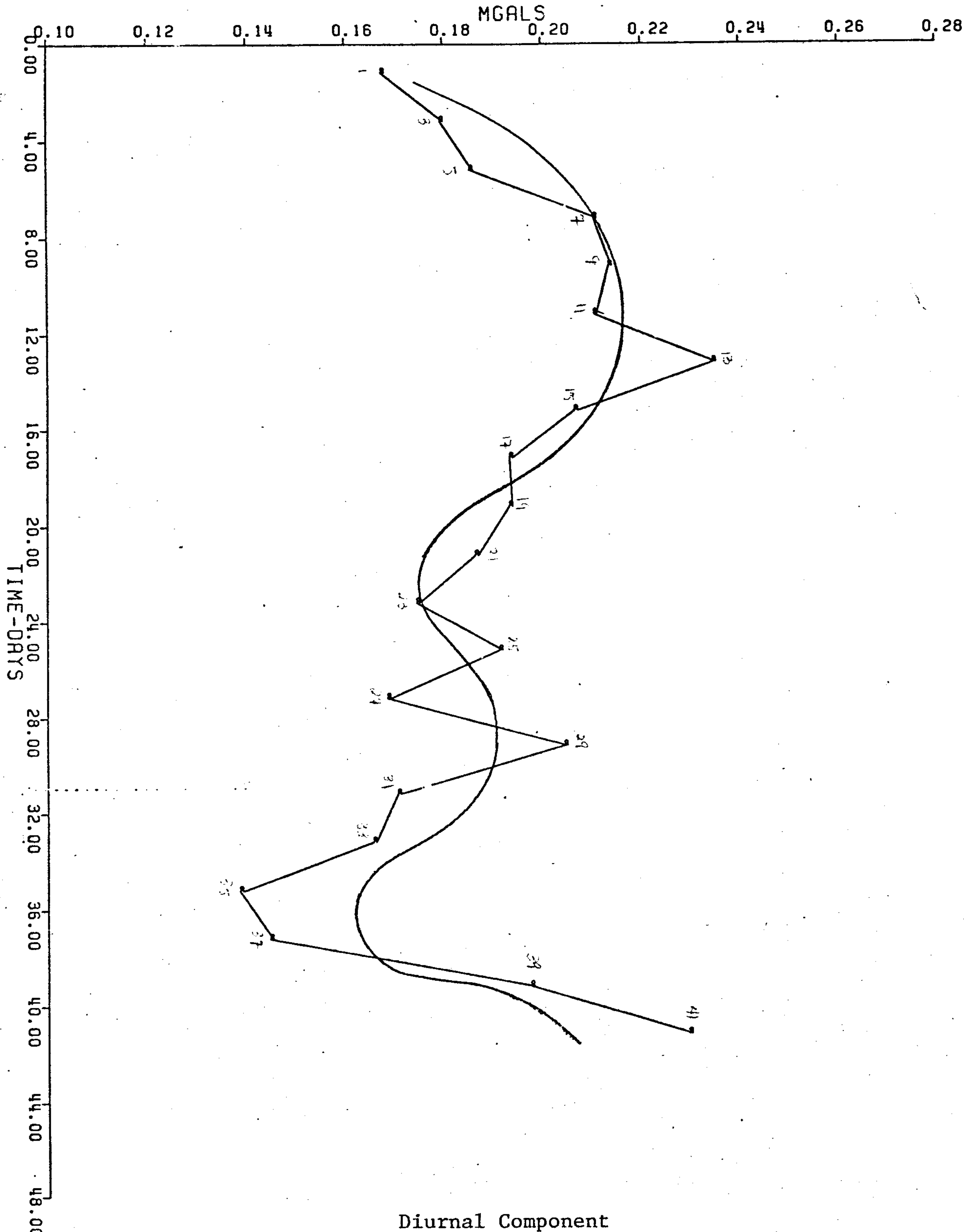
Semi-diurnal Component
weekly period - fourteenth harmonic
data grouped & analyzed between noon and following noon
smooth curve reflects general trend of data



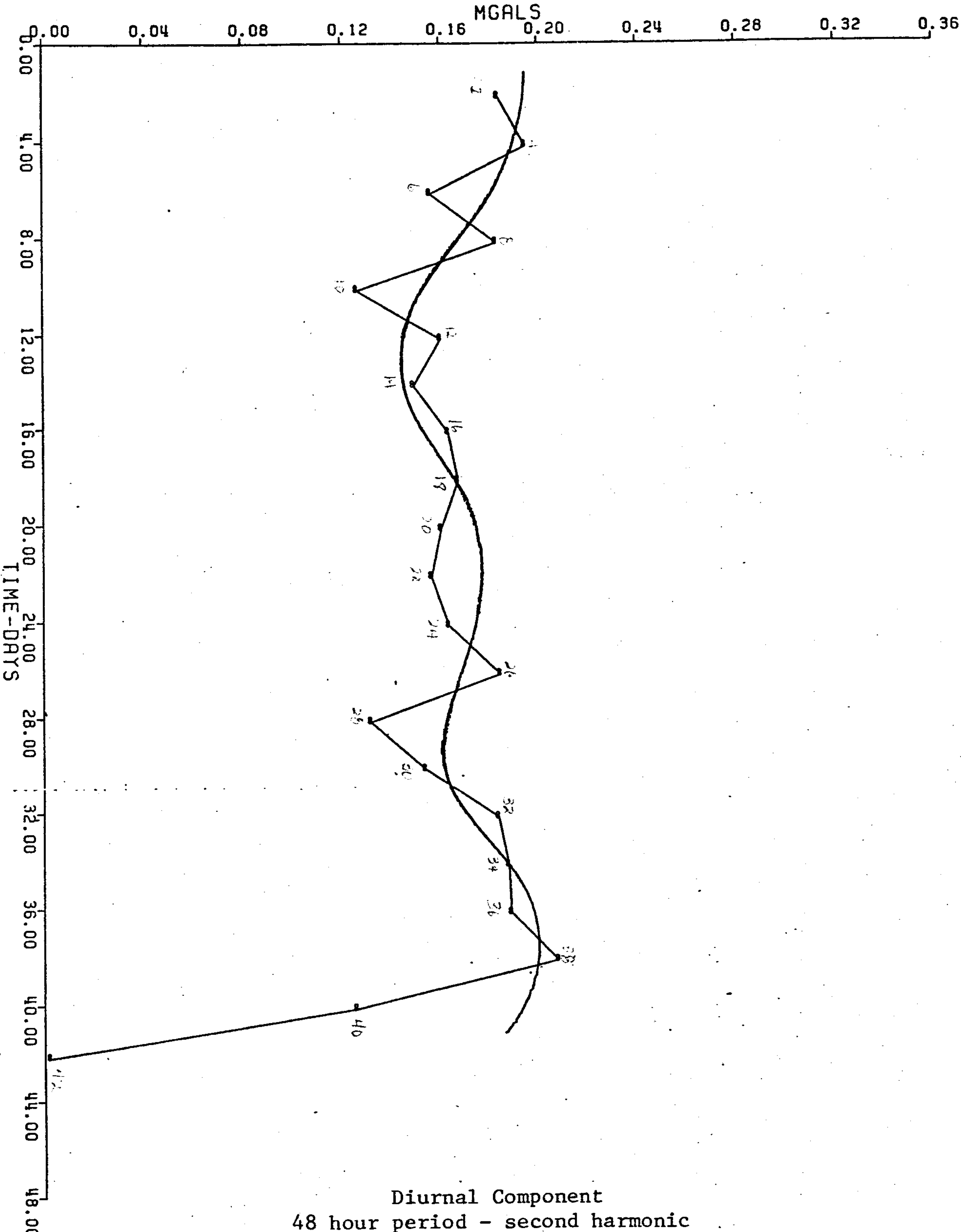
Semi-diurnal Component
weekly period - fourteenth harmonic
data grouped & analyzed from midnight to midnight
smooth curve reflects general trend of data



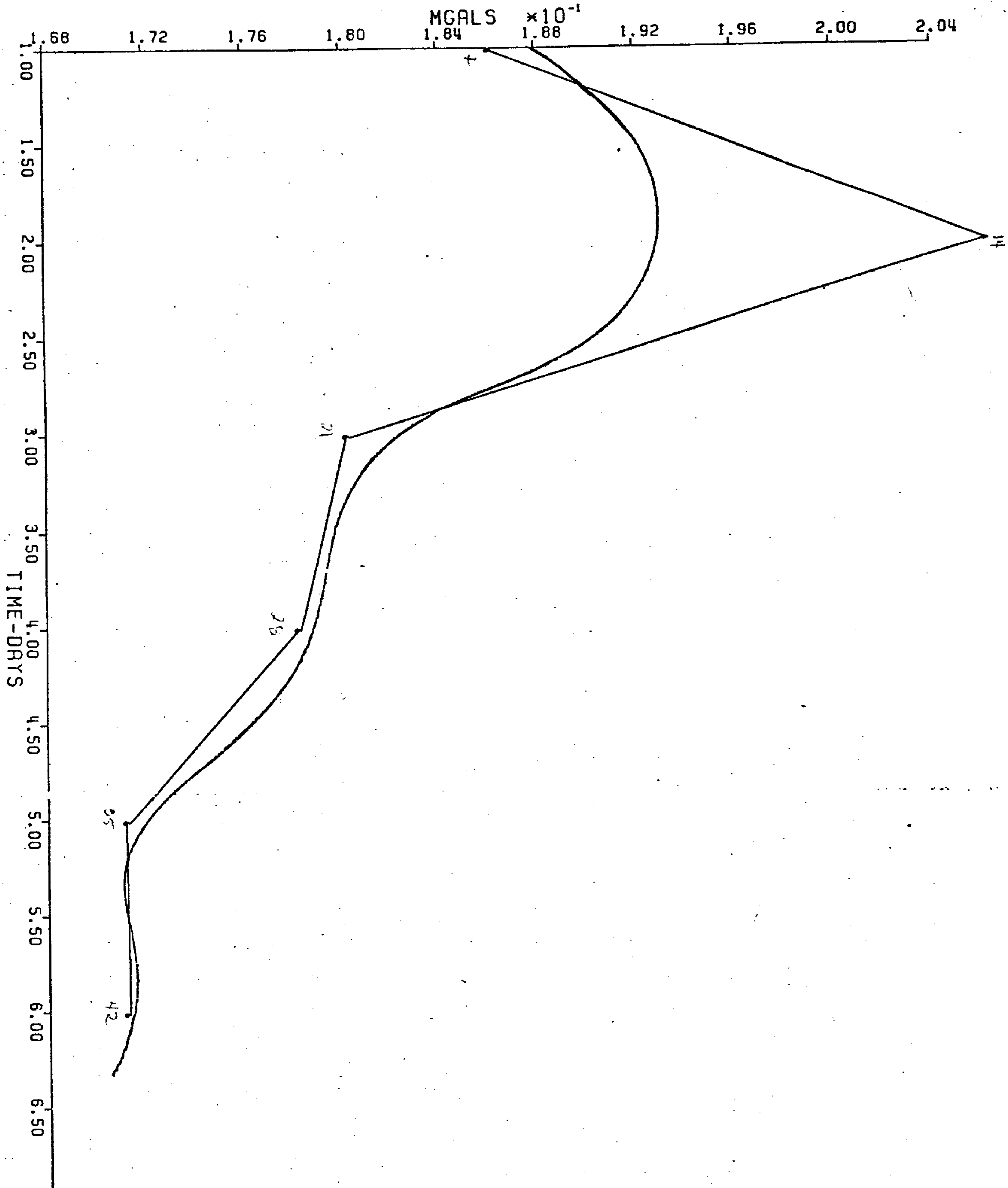
Diurnal Component
24 hour period - first harmonic
smooth curve reflects general trend of data



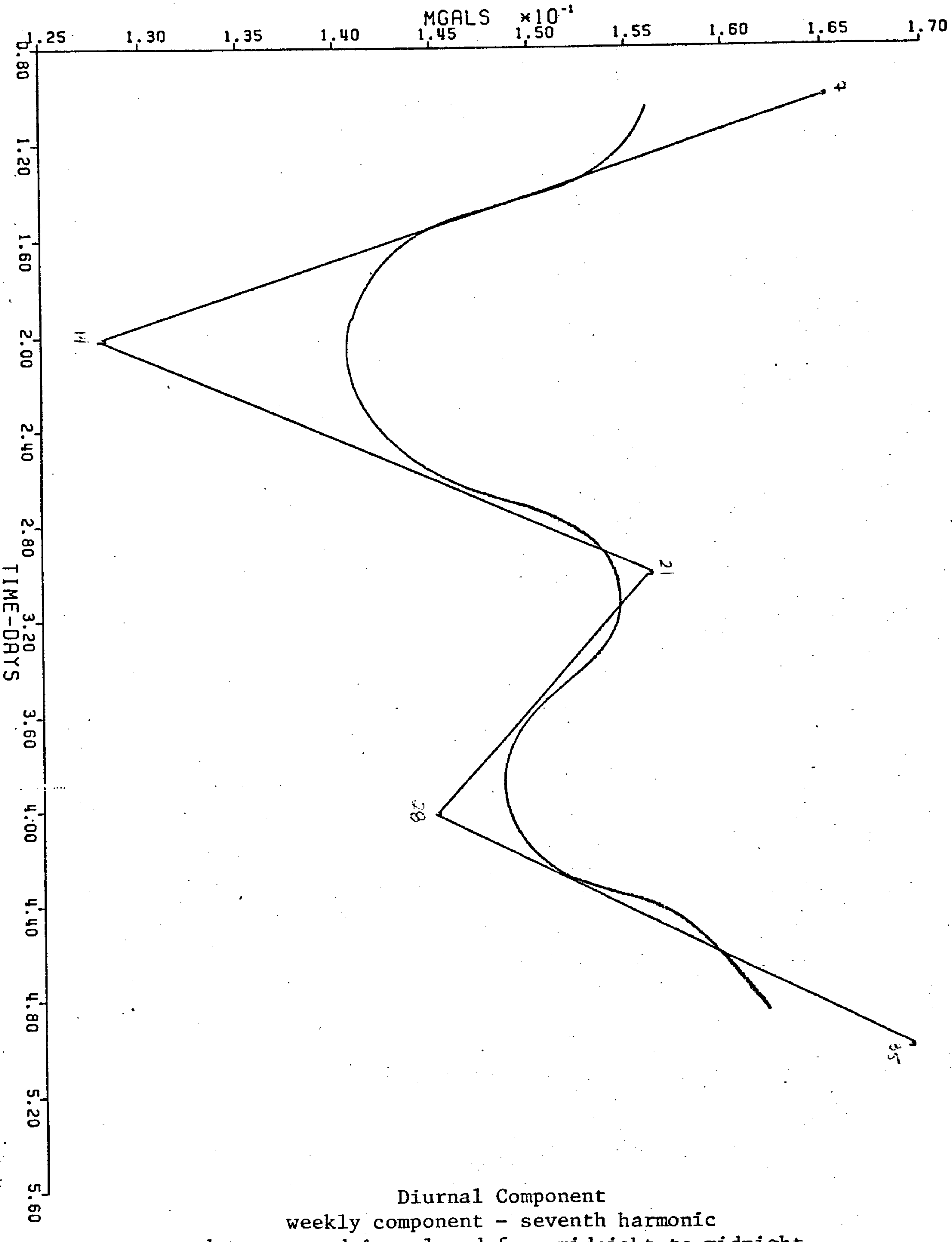
Diurnal Component
48 hour period - second harmonic
data grouped & analyzed between noon and following noon
smooth curve reflects general trend of data



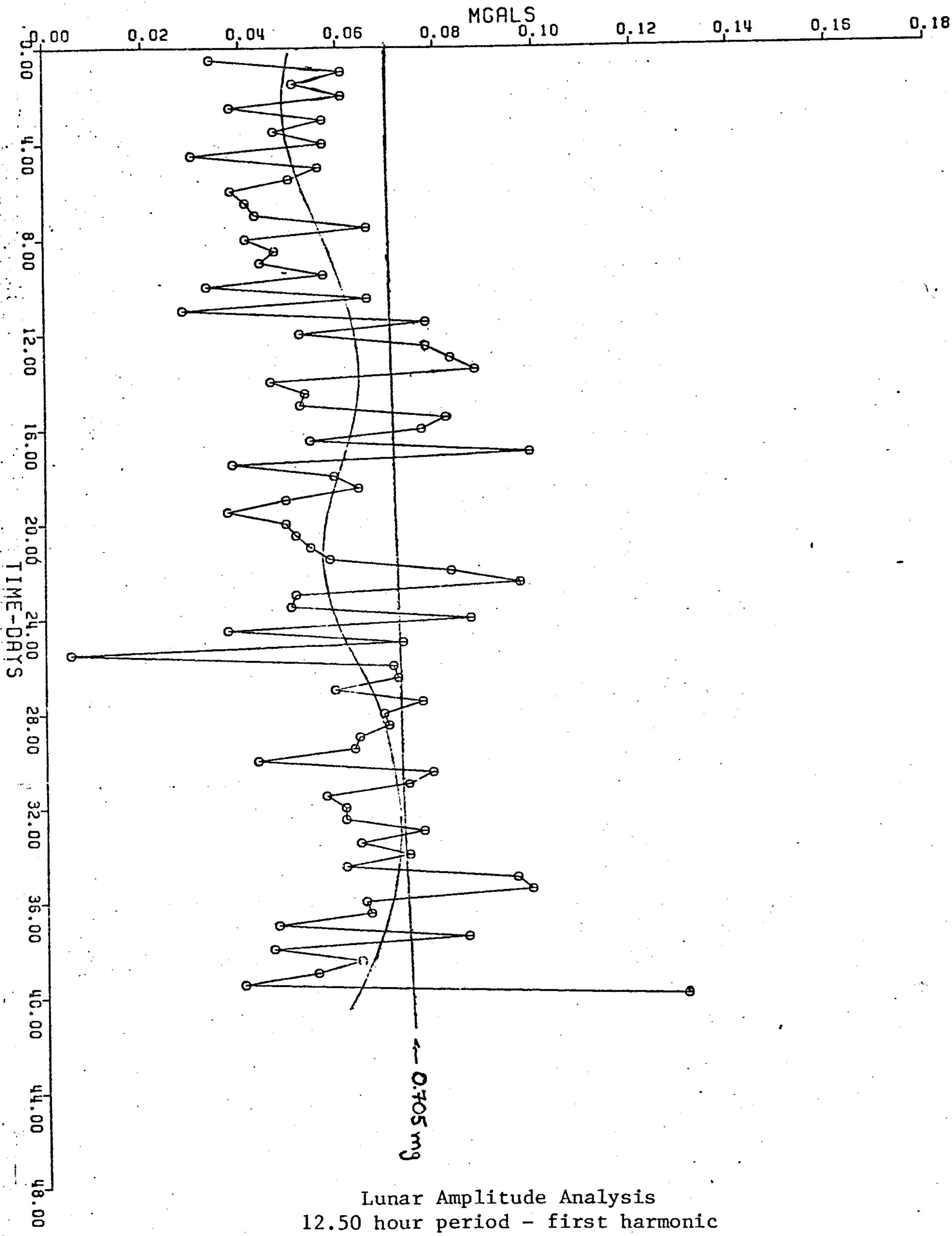
Diurnal Component
48 hour period - second harmonic
data grouped & analyzed from midnight to midnight
smooth curve reflects general trend of data



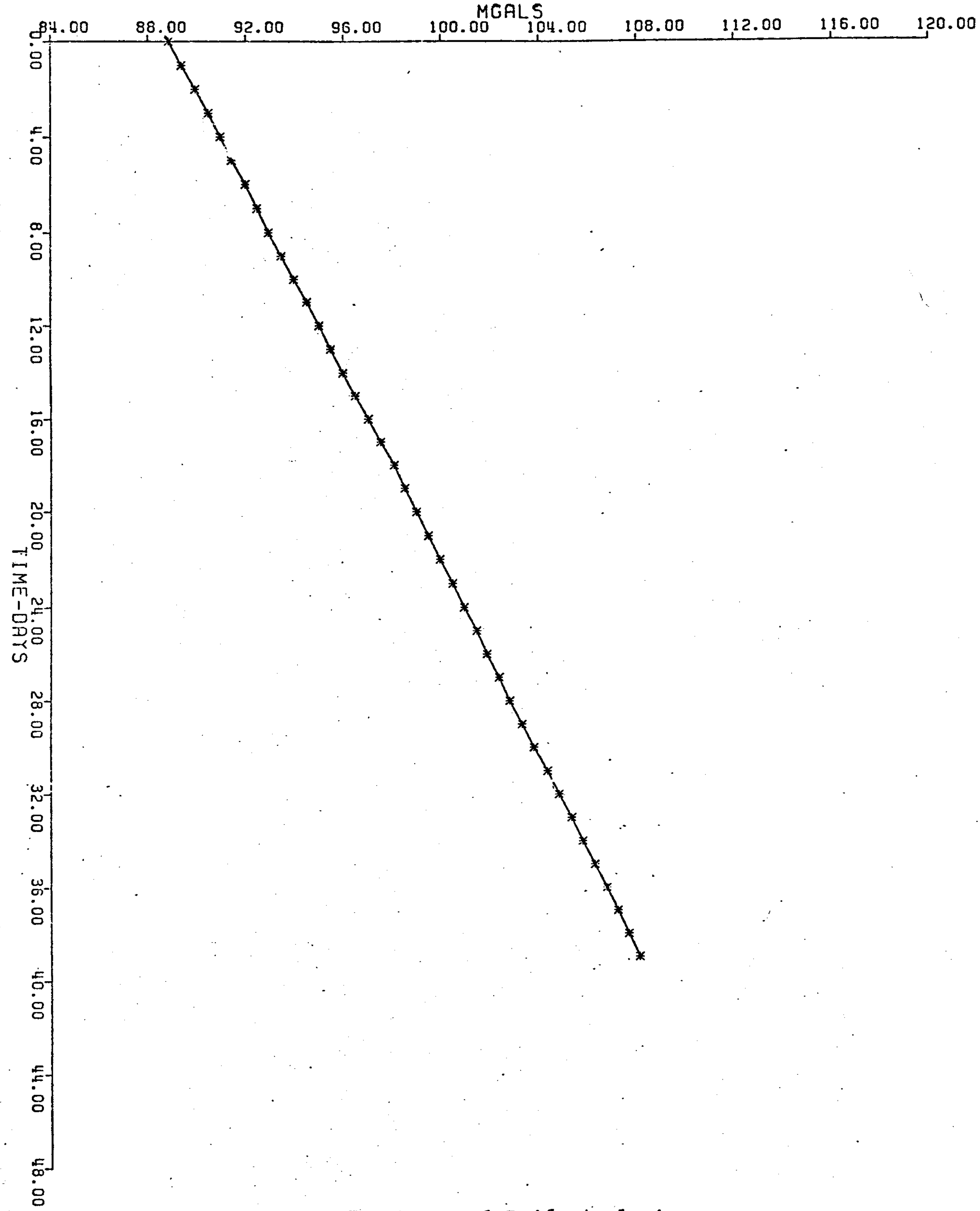
Diurnal Component
weekly component - seventh harmonic
data grouped & analyzed between noon and following noon
smooth curve reflects general trend of data



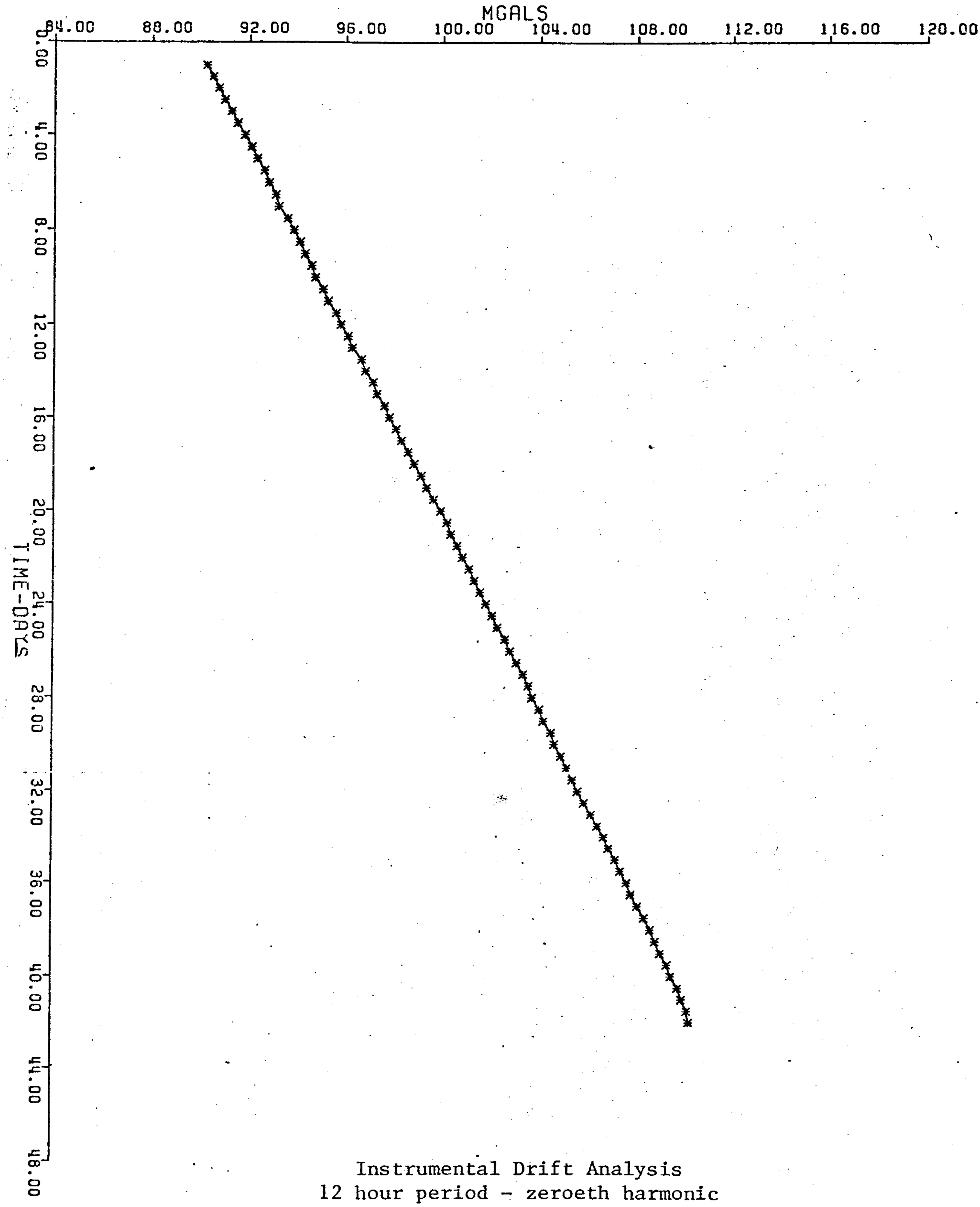
Diurnal Component
weekly component - seventh harmonic
data grouped & analyzed from midnight to midnight
smooth curve reflects general trend of data



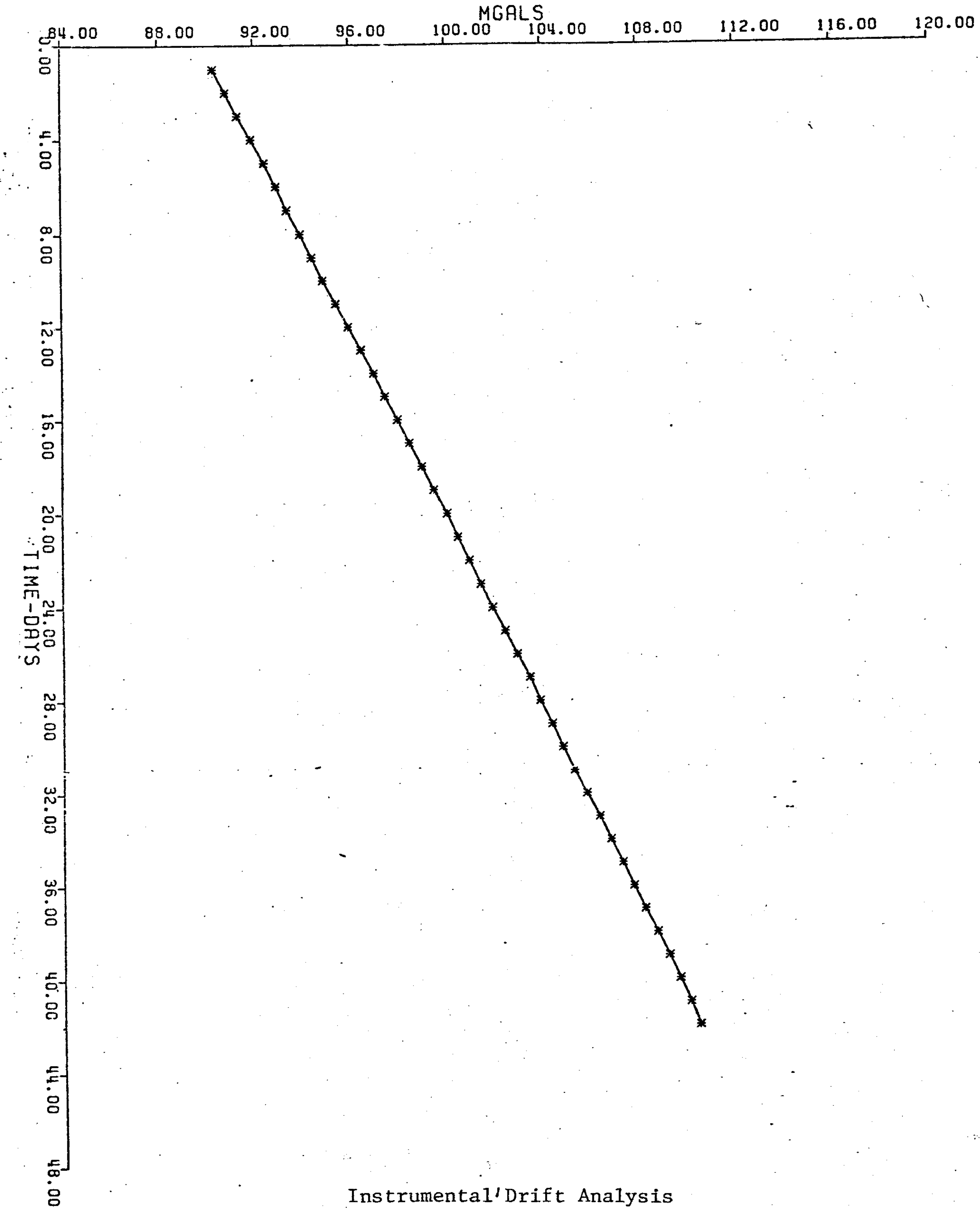
Lunar Amplitude Analysis
12.50 hour period - first harmonic
horizontal line represents average lunar amplitude
smooth curve reflects general trend of data



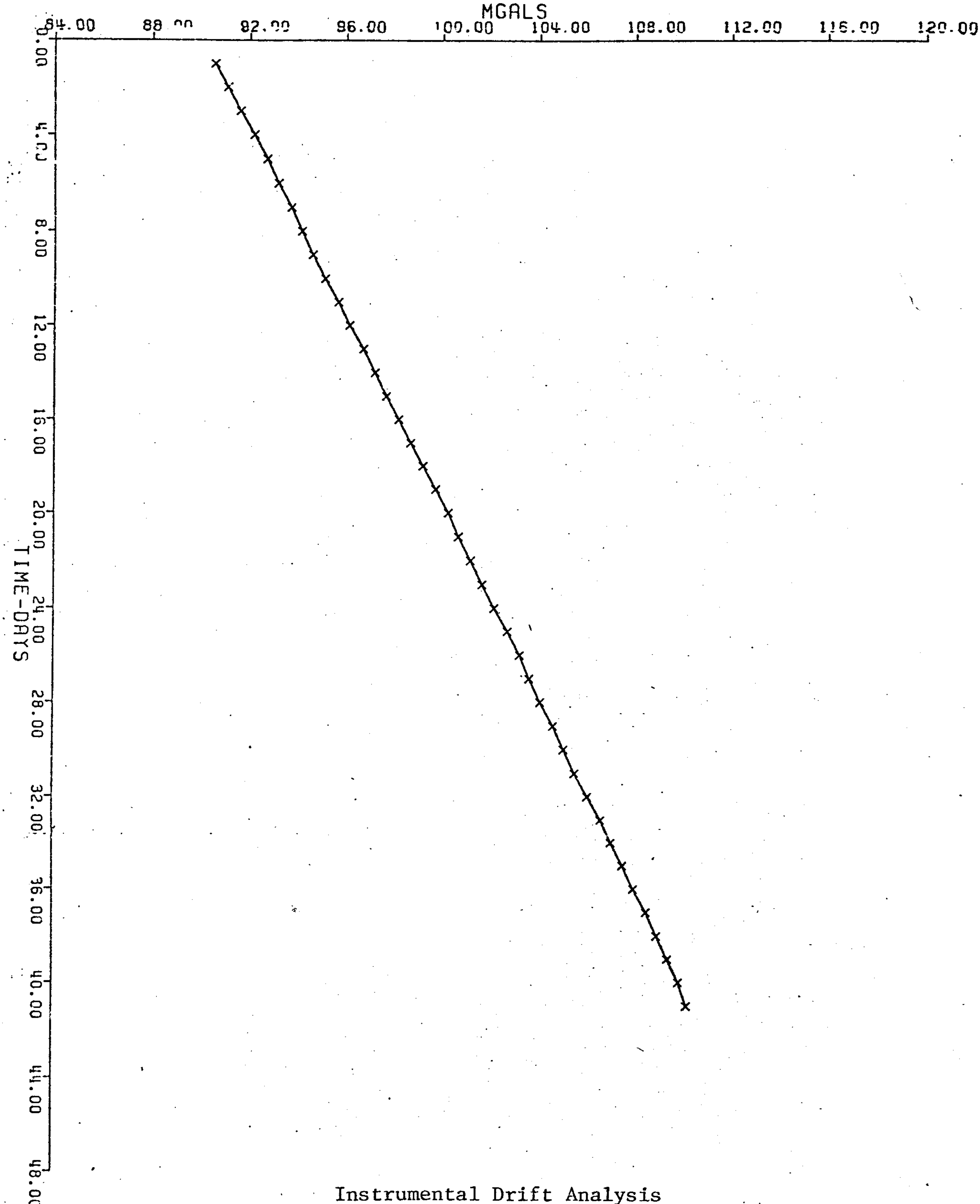
Instrumental Drift Analysis
12 hour period - zeroeth harmonic
data grouped & analyzed between 6:00 a.m. and 6:00 p.m.



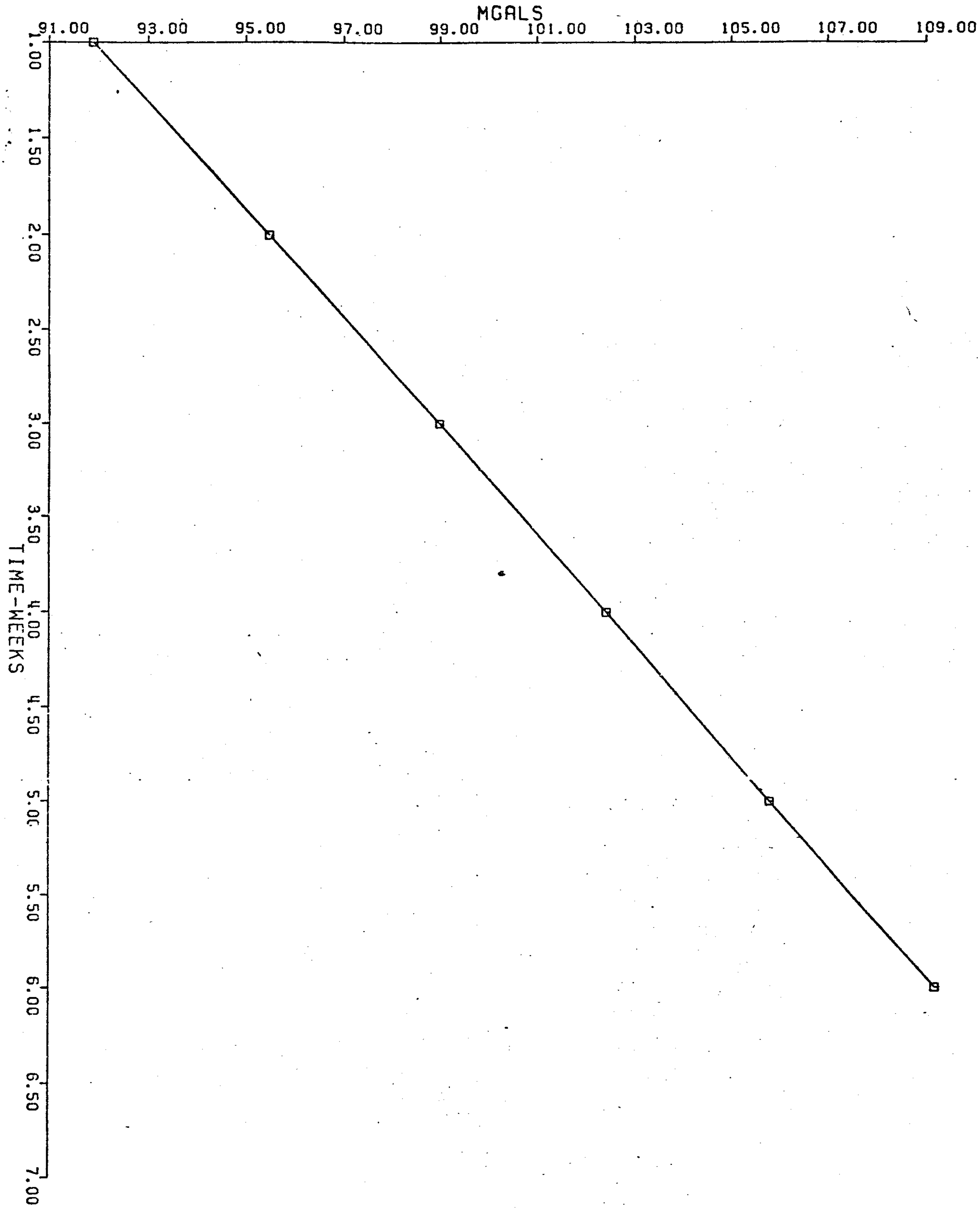
Instrumental Drift Analysis
12 hour period - zeroeth harmonic
data grouped & analyzed from midnight to noon then noon to midnight



Instrumental Drift Analysis
24 hour period - zeroeth harmonic
data grouped & analyzed from noon to following noon



Instrumental Drift Analysis
48 hour period - zeroeth harmonic
data grouped & analyzed from noon to noon and from midnight to midnight



Instrumental Drift Analysis
weekly period - zeroeth harmonic

APPENDIX II:

GRAVITY AND HARMONIC ANALYSIS DATA

Relative Gravity Measurements Collected from 2/18/82 to 3/31/82

Date	Time	Left Reading (mgals)	Mid Reading (mgals)	Right Reading (mgals)	Temp (°F)	Dial Const.	$\frac{(L+M+R)}{3}$ (mgals)	Relative Gravity (mgals)
2/18/82	12:05	1011.3	1048.1	1091.4	69	.08574	1050.267	90.050
	13:14	1011.9	1049.2	1092.2	70	.08575	1051.100	90.132
	14:52	1012.3	1049.6	1092.2	71	.08576	1051.367	90.165
	16:02	1012.3	1049.2	1093.8	71	.08576	1051.767	90.200
	20:03	1010.8	1048.5	1092.2	71	.08576	1050.500	90.091
2/19/82	5:25	1015.9	1053.2	1095.7	72	.08576	1054.933	90.471
	8:00	1015.6	1053.0	1095.1	72	.08576	1054.567	90.440
	11:50	1017.3	1054.6	1098.1	72	.08576	1056.667	90.620
	15:30	1017.8	1054.9	1098.1	72	.08576	1056.933	90.643
	20:01	1018.5	1055.3	1098.2	72	.08576	1057.333	90.677
2/20/82	8:30	1022.0	1058.9	1101.6	72	.08576	1060.833	90.977
	10:00	1022.9	1059.8	1102.6	72	.08576	1061.767	91.057
	12:00	1022.8	1059.9	1102.7	73	.08577	1061.800	91.071
	16:04	1024.6	1062.0	1105.2	74	.08578	1063.933	91.264
2/21/82	9:03	1027.8	1064.3	1107.3	73	.08577	1066.467	91.471
	11:57	1029.5	1065.7	1108.0	73	.08577	1067.733	91.579
	16:02	1029.8	1067.3	1111.5	73	.08577	1069.533	91.734
	19:52	1031.2	1069.1	1112.3	73	.08577	1070.867	91.848
2/22/82	5:26	1033.5	1071.2	1114.5	73	.08577	1073.067	92.037
	8:00	1035.2	1072.7	1115.2	73	.08577	1074.367	92.148
	10:23	1034.5	1072.4	1116.2	73	.08577	1074.367	92.148
	12:00	1035.0	1071.7	1115.4	73	.08577	1074.033	92.120
	16:00	1037.5	1074.8	1118.0	73	.08577	1076.766	92.354
	20:36	1037.1	1074.1	1116.6	73	.08577	1075.933	92.283
2/23/82	5:21	1040.7	1077.8	1121.1	73	.08577	1079.866	92.620
	7:48	1040.9	1077.9	1121.9	73	.08577	1080.233	92.652
	11:44	1041.5	1078.9	1122.4	73	.08577	1080.933	92.712
	15:48	1042.4	1079.5	1122.4	73	.08577	1081.433	92.758
	18:00	1043.5	1080.6	1123.4	73	.08577	1082.500	92.846
	20:00	1042.9	1080.0	1123.4	73	.08577	1082.100	92.812
2/24/82	5:18	1046.0	1083.3	1126.3	73	.08577	1085.200	93.078
	7:52	1046.5	1083.4	1126.3	73	.08577	1085.400	93.095
	11:55	1047.4	1084.3	1128.0	73	.08577	1086.567	93.195
	13:51	1047.5	1084.7	1128.0	72	.08576	1086.733	93.198
	19:57	1050.2	1087.3	1130.5	72	.08576	1089.333	93.421
2/25/82	5:28	1051.3	1088.5	1131.9	72	.08576	1090.567	93.527
	8:00	1053.5	1091.0	1133.9	72	.08576	1092.800	93.719
	12:00	1052.7	1089.5	1132.8	72	.08576	1091.667	93.621
	14:07	1053.8	1091.2	1133.9	72	.08576	1092.967	93.733
	15:38	1053.9	1090.9	1134.1	72	.08576	1092.967	93.733
	20:00	1056.9	1094.2	1137.3	72	.08576	1096.133	94.004
2/26/82	5:23	1056.9	1094.2	1137.3	72	.08576	1096.133	94.004
	7:52	1059.0	1096.2	1139.8	72	.08576	1098.333	94.193
	11:55	1058.5	1095.9	1139.3	72	.08576	1097.900	94.156
	16:00	1059.7	1096.6	1139.7	72	.08576	1098.667	94.222
	20:15	1060.7	1098.0	1141.8	73	.08577	1100.167	94.361
2/27/82	9:40	1064.7	1101.7	1145.3	74	.08578	1103.900	94.693
	11:55	1063.7	1100.4	1149.1	75	.08578	1102.733	94.592
	16:00	1064.4	1101.0	1144.5	75	.08578	1103.300	94.641
	18:10	1064.5	1101.0	1144.5	75	.08578	1103.333	94.644
2/28/82	12:05	1070.9	1108.2	1151.5	76	.08579	1110.200	95.244
	14:10	1069.0	1107.3	1150.0	76	.08579	1108.767	95.121
	15:30	1069.9	1107.1	1150.5	76	.08579	1109.167	95.155
	20:05	1071.3	1108.3	1151.2	76	.08579	1110.267	95.250

Relative Gravity Measurements Collected from 2/18/82 to 3/31/82

Date	Time	Left Reading (mgals)	Mid Reading (mgals)	Right Reading (mgals)	Temp (°F)	Dial Const.	(L+M+R)/3 (mgals)	Relative Gravity (mgals)
3/ 1/82	5:23	1074.3	1112.1	1155.8	76	.08579	1114.067	95.576
	7:52	1074.6	1112.0	1155.8	76	.08679	1114.133	95.581
	11:54	1077.0	1114.2	1158.2	76	.08579	1116.467	95.782
	15:54	1075.1	1112.1	1156.4	76	.08579	1114.533	95.616
	19:50	1077.4	1114.8	1158.2	76	.08579	1116.800	95.810
3/ 2/82	5:20	1079.2	1117.5	1161.2	76	.08579	1119.300	96.023
	8:48	1081.1	1119.1	1163.6	76	.08579	1121.267	96.193
	11:57	1081.1	1119.0	1163.7	76	.08579	1121.267	96.193
	15:45	1081.1	1120.1	1163.7	76	.08579	1121.333	96.199
	19:55	1081.5	1119.7	1163.7	76	.08579	1121.633	96.245
3/ 3/82	5:20	1086.5	1125.0	1168.9	74	.08578	1126.800	96.657
	7:53	1086.5	1124.3	1168.9	74	.08578	1126.567	96.637
	11:53	1089.0	1126.7	1171.2	74	.08578	1128.967	96.843
	16:00	1087.7	1125.8	1169.4	74	.08578	1127.633	96.728
	20:00	1088.7	1126.6	1171.0	74	.08578	1128.767	96.826
3/ 4/82	5:20	1091.3	1130.0	1174.3	74	.08578	1131.867	97.092
	7:57	1092.7	1131.5	1176.0	74	.08578	1133.400	97.223
	12:03	1092.2	1131.6	1176.6	75	.08578	1133.267	97.212
	16:00	1094.1	1132.5	1177.0	76	.08579	1134.533	97.332
	19:55	1092.1	1130.8	1174.7	76	.08579	1132.533	97.160
3/ 5/82	5:00	1097.5	1136.0	1181.0	76	.08579	1138.167	97.643
	8:00	1096.9	1135.3	1181.0	76	.08579	1137.800	97.612
	12:20	1098.1	1137.0	1182.8	76	.08579	1139.300	97.741
	15:50	1099.5	1137.7	1182.9	76	.08579	1139.700	97.775
	19:38	1099.5	1138.2	1183.1	76	.08579	1140.267	97.823
3/ 6/82	8:00	1103.0	1141.7	1187.0	75	.08578	1143.900	98.124
	12:00	1103.9	1143.5	1188.5	76	.08579	1145.300	98.255
	15:52	1105.0	1143.8	1189.2	76	.08579	1146.000	98.315
	20:08	1101.6	1144.0	1188.8	76	.08579	1144.800	98.212
3/ 7/82	9:45	1107.8	1147.9	1193.3	76	.08579	1149.667	98.630
	12:00	1109.0	1148.6	1194.9	76	.08579	1150.833	98.730
	14:00	1108.7	1149.0	1194.9	76	.08579	1150.867	98.733
	16:00	1110.7	1150.7	1196.7	76	.08579	1152.700	98.890
	20:00	1110.3	1149.8	1194.5	76	.08579	1151.533	98.790
3/ 8/82	5:17	1114.9	1153.8	1199.0	76	.08579	1155.900	99.165
	8:03	1114.6	1153.9	1199.0	76	.08579	1155.833	99.159
	11:52	1115.4	1154.6	1199.1	75	.08578	1156.367	99.193
	16:03	1116.9	1155.3	1200.1	75	.08578	1157.433	99.285
	20:00	1118.3	1155.2	1202.5	76	.08579	1158.667	99.402
3/ 9/82	5:20	1119.3	1158.6	1203.7	76	.08579	1160.533	99.562
	8:00	1121.2	1160.4	1206.3	76	.08579	1162.633	99.742
	11:53	1119.8	1159.2	1204.3	75	.08578	1161.100	99.600
	16:00	1123.1	1162.4	1207.5	74	.08578	1164.333	99.877
	20:00	1123.0	1162.8	1207.9	74	.08578	1164.567	99.897
3/10/82	5:30	1126.8	1166.3	1212.2	75	.08578	1168.433	100.228
	8:00	1126.3	1166.3	1212.2	75	.08578	1168.267	100.214
	11:52	1127.1	1166.5	1212.3	76	.08579	1168.633	100.257
	14:35	1126.1	1166.2	1212.3	75	.08578	1168.200	100.208
	16:00	1127.8	1167.4	1212.5	76	.08579	1169.233	100.309
	20:08	1128.4	1167.9	1213.6	76	.08579	1169.967	100.372
3/11/82	5:20	1130.5	1170.5	1216.5	77	.08579	1172.500	100.589
	8:00	1131.1	1170.9	1216.9	77	.08579	1172.967	100.629
	12:00	1131.1	1171.5	1218.2	77	.08579	1173.600	100.683
	16:00	1131.3	1171.7	1218.2	77	.08579	1173.733	100.695

Relative Gravity Measurements Collected from 2/18/82 to 3/31/82

Date	Time	Left Reading (mgals)	Mid Reading (mgals)	Right Reading (mgals)	Temp (°F)	Dial Const.	(L+M+R)/3 (mgals)	Relative Gravity (mgals)
3/11/82	20:00	1134.8	1175.0	1220.6	77	.08579	1176.800	100.958
3/12/82	8:00	1136.5	1176.5	1222.9	76	.08579	1178.633	101.115
	11:52	1137.8	1177.6	1224.0	76	.08579	1179.800	101.215
	15:52	1137.6	1177.6	1224.0	76	.08579	1179.733	101.209
	20:40	1141.2	1180.8	1226.5	76	.08579	1182.833	101.475
3/13/82	4:30	1140.8	1180.5	1226.5	77	.08579	1182.600	101.455
	8:00	1143.5	1183.4	1228.6	77	.08579	1185.167	101.676
	12:00	1142.4	1182.1	1228.3	76	.08579	1184.267	101.598
	15:27	1144.9	1183.3	1226.5	76	.08579	1184.900	101.653
	16:00	1143.6	1183.4	1229.0	76	.08579	1185.333	101.690
	19:50	1146.1	1186.2	1232.1	76	.08579	1188.133	101.930
3/14/82	11:25	1148.2	1188.7	1235.9	76	.08579	1190.933	102.170
	15.27	1149.6	1189.9	1234.5	75	.08578	1191.333	102.205
3/15/82	6:00	1153.4	1193.8	1240.2	74	.08578	1195.800	102.588
	8:00	1154.7	1195.5	1241.9	73	.08577	1197.367	102.722
	11:55	1154.3	1195.2	1241.9	73	.08577	1197.133	102.702
	16:00	1155.5	1196.3	1243.6	73	.08577	1198.467	102.817
	20:00	1155.9	1196.8	1243.6	72	.08576	1198.767	102.842
3/16/82	5:20	1160.4	1201.0	1247.3	72	.08576	1202.933	103.200
	8:00	1159.8	1200.6	1247.8	72	.08576	1202.733	103.183
	16:05	1161.9	1202.9	1250.3	73	.08577	1205.033	103.380
	19:30	1161.8	1201.9	1248.6	74	.08578	1204.100	103.300
3/17/82	5:12	1165.0	1205.0	1250.8	75	.08578	1206.933	103.543
	7:40	1164.8	1205.1	1251.3	75	.08578	1207.067	103.554
	12:00	1166.4	1206.8	1253.9	76	.08579	1209.033	103.723
	16:02	1164.8	1205.8	1252.3	76	.08579	1207.633	103.603
	19:15	1166.8	1207.4	1253.5	75	.08578	1209.233	103.740
/18/82	8:10	1169.5	1210.4	1257.6	76	.08579	1212.500	104.020
	12:05	1171.7	1212.4	1258.6	76	.08579	1214.233	104.169
	16:00	1170.6	1211.5	1258.6	76	.08579	1213.567	104.112
	20:00	1172.2	1213.0	1259.4	76	.08579	1214.867	104.223
3/19/82	7:50	1175.2	1215.6	1262.9	76	.08579	1217.900	104.484
	11:58	1177.1	1218.2	1265.5	76	.08579	1220.267	104.687
	13:59	1176.7	1217.9	1264.4	76	.08579	1219.667	104.635
	16:00	1177.5	1218.8	1265.2	76	.08579	1220.500	104.707
	18:00	1177.4	1217.5	1264.7	76	.08579	1219.867	104.652
	20:00	1177.5	1218.5	1261.0	76	.08579	1219.900	104.578
	22:03	1177.1	1218.3	1264.9	76	.08579	1220.100	104.672
	24:00	1179.9	1219.9	1266.0	76	.08579	1221.933	104.830
3/20/82	8:07	1181.2	1221.2	1268.0	76	.08579	1223.467	104.961
	10:00	1182.2	1222.3	1269.3	76	.08579	1224.600	105.058
	11:58	1180.9	1222.3	1268.5	76	.08579	1223.900	104.998
	13:57	1183.3	1224.3	1270.7	76	.08579	1226.100	105.187
	16:03	1182.7	1223.6	1270.5	76	.08579	1225.600	105.144
	18:04	1183.3	1224.8	1271.5	76	.08579	1226.533	105.224
	20:00	1181.8	1223.1	1269.9	76	.08579	1224.933	105.087
	22:00	1183.3	1224.2	1269.8	77	.08579	1225.800	105.161
3/21/82	6:00	1186.2	1226.8	1272.8	77	.08579	1228.600	105.402
	8:02	1187.4	1227.6	1273.8	77	.08579	1229.600	105.487
	10:00	1186.7	1227.2	1272.9	77	.08579	1228.933	105.430
	12:00	1188.3	1228.2	1274.3	77	.08579	1230.267	105.545
	14:00	1187.8	1228.4	1274.2	77	.08579	1230.133	105.533
	16:00	1189.9	1229.9	1276.0	77	.08579	1231.933	105.688
	18:00	1188.9	1228.9	1275.4	76	.08579	1231.067	105.613
	20:00	1189.6	1230.3	1276.3	76	.08579	1232.067	105.699

Relative Gravity Measurements Collected from 2/18/82 to 3/31/82

Date	Time	Left Reading (mgals)	Mid Reading (mgals)	Right Reading (mgals)	Temp (°F)	Dial Const.	(L+M+R)/3 (mgals)	Relative Gravity (mgals)
3/22/82	8:03	1192.8	1233.4	1280.2	76	.08579	1235.467	105.990
	10:00	1193.7	1234.3	1279.7	76	.08579	1235.900	106.028
	12:04	1193.6	1233.4	1279.4	76	.08579	1235.467	105.990
	14:02	1195.2	1235.5	1281.5	76	.08579	1237.400	106.157
	16:00	1195.1	1235.7	1281.3	76	.08579	1237.367	106.154
	18:00	1196.3	1237.2	1282.8	76	.08579	1238.767	106.274
	20:00	1195.5	1236.8	1281.3	76	.08579	1237.867	106.197
3/23/82	6:00	1200.5	1240.7	1286.3	76	.08579	1242.500	106.594
	8:05	1199.4	1239.7	1285.7	76	.08579	1241.600	106.517
	10:02	1199.9	1240.2	1286.2	76	.08579	1242.100	106.560
	12:00	1199.1	1239.6	1285.4	76	.08579	1241.367	106.492
	14:05	1201.1	1241.8	1287.3	76	.08579	1243.667	106.694
	15:55	1201.3	1241.4	1287.3	76	.08579	1243.333	106.666
	18:00	1203.2	1243.3	1288.7	76	.08579	1245.067	106.814
	20:00	1201.6	1241.8	1288.0	76	.08579	1243.800	106.706
3/24/82	8:00	1206.7	1246.7	1292.3	76	.08579	1248.333	107.095
	10:07	1205.1	1244.9	1290.0	76	.08579	1246.667	106.952
	12:10	1205.6	1245.8	1290.7	76	.08579	1247.367	107.012
	14:00	1205.3	1245.8	1292.2	76	.08579	1247.767	107.046
	16:00	1207.3	1247.9	1294.6	76	.08579	1249.933	107.213
	18:05	1207.6	1247.7	1294.1	76	.08579	1249.800	107.220
	20:00	1208.7	1249.0	1295.1	76	.08579	1250.933	107.318
	21:58	1207.3	1247.6	1293.4	76	.08579	1249.433	107.189
3/25/82	8:00	1212.8	1252.4	1298.1	75	.08578	1254.433	107.618
	10:10	1211.0	1251.4	1297.5	75	.08578	1253.300	107.521
	12:04	1211.4	1251.9	1296.9	75	.08578	1253.400	107.529
	14:00	1210.8	1251.1	1296.6	74	.08578	1252.833	107.481
	16:00	1213.3	1253.0	1298.8	74	.08578	1255.033	107.669
	18:17	1213.1	1253.2	1299.3	74	.08578	1255.367	107.698
	19:00	1214.9	1254.9	1299.9	74	.08578	1256.567	107.801
	20:00	1214.4	1254.1	1299.7	74	.08578	1256.067	107.758
	21:00	1214.9	1255.0	1300.1	74	.08578	1256.667	107.809
3/26/82	7:58	1218.1	1256.9	1301.9	73	.08577	1258.967	107.982
	10:03	1217.5	1257.6	1303.5	73	.08577	1259.533	108.030
	12:08	1215.7	1256.2	1302.4	72	.08576	1258.100	107.895
	14:00	1211.9	1257.4	1303.3	72	.08576	1257.533	107.846
	16:01	1217.4	1257.9	1305.4	72	.08576	1260.233	108.078
	18:02	1219.3	1260.6	1307.5	72	.08576	1262.467	108.269
	20:04	1219.6	1260.6	1307.2	72	.08576	1262.467	108.269
3/27/82	8:03	1224.1	1265.3	1312.1	71	.08575	1267.167	108.660
	12:10	1221.6	1263.2	1310.4	70	.08575	1265.067	108.480
	16:00	1223.6	1264.7	1311.9	70	.08575	1266.733	108.622
	20:00	1225.8	1266.5	1313.9	70	.08575	1268.733	108.794
3/28/82	12:00	1229.3	1270.6	1317.3	70	.08575	1272.400	109.108
	16:02	1227.8	1268.7	1316.1	70	.08575	1270.867	108.977
	20:00	1231.4	1271.8	1319.1	70	.08575	1274.100	109.254
3/29/83	5:15	1231.6	1272.6	1319.9	71	.08576	1274.700	109.318
	9:55	1233.6	1275.5	1323.2	71	.08576	1277.433	109.552
	13:50	1231.7	1273.5	1320.0	71	.08576	1275.667	109.350
	16:08	1232.6	1274.5	1322.6	70	.08575	1276.567	109.478

Relative Gravity Measurements Collected from 2/18/82 to 3/31/82

Date	Time	Left Reading (mgals)	Mid Reading (mgals)	Right Reading (mgals)	Temp (°F)	Dial Const.	$\frac{(L+M+R)}{3}$ (mgals)	Relative Gravity (mgals)
3/30/82	5:15	1236.6	1277.8	1325.9	71	.08576	1280.100	109.781
	9:52	1238.5	1280.3	1327.6	71	.08576	1282.133	109.956
	12:30	1237.2	1279.1	1327.7	71	.08576	1281.333	109.887
	17:10	1237.8	1279.8	1327.6	72	.08577	1281.733	109.934
3/31/82	5:20	1240.8	1282.3	1329.7	72	.08577	1284.267	110.152
	9:55	1243.6	1284.2	1330.7	72	.08577	1286.167	110.315
	14:55	1242.8	1282.6	1329.0	71	.08576	1284.800	110.185
	16:59	1243.3	1283.8	1329.8	71	.08576	1285.633	110.256
	19:10	1242.9	1283.1	1330.0	71	.08576	1285.333	110.230

Readings Extracted from Gravity-Time Curve at 3 Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
2/18/82	12:00	90.050	2/25/82	3:00	93.440
	15:00	90.165		6:00	93.540
	18:00	90.230		9:00	93.760
	21:00	90.220		12:00	93.621
	24:00	90.280		15:00	93.740
2/19/82	3:00	90.350		18:00	93.900
	6:00	90.450		21:00	93.820
	9:00	90.480		24:00	93.880
	12:00	90.620	2/26/82	3:00	93.960
	15:00	90.640		6:00	94.030
	18:00	90.650		9:00	94.220
	21:00	90.740		12:00	94.156
	24:00	90.810		15:00	94.160
2/20/82	3:00	90.870		18:00	94.270
	6:00	90.940		21:00	94.370
	9:00	90.990		24:00	94.400
	12:00	91.071	2/27/82	3:00	94.470
	15:00	91.170		6:00	94.520
	18:00	91.200		9:00	94.730
	21:00	91.260		12:00	94.592
	24:00	91.340		15:00	94.580
2/21/82	3:00	91.400		18:00	94.644
	6:00	91.460		21:00	94.840
	9:00	91.471		24:00	94.880
	12:00	91.579	2/28/82	3:00	94.920
	15:00	91.680		6:00	95.020
	18:00	91.810		9:00	95.070
	21:00	91.780		12:00	95.244
	24:00	91.840		15:00	95.150
2/22/82	3:00	91.930		18:00	95.200
	6:00	92.040		21:00	95.320
	9:00	92.140		24:00	95.370
	12:00	92.120	3/ 1/82	3:00	95.430
	15:00	92.230		6:00	95.580
	18:00	92.380		9:00	95.600
	21:00	92.280		12:00	95.782
	24:00	92.350		15:00	95.720
2/23/82	3:00	92.420		18:00	95.780
	6:00	92.660		21:00	95.820
	9:00	92.610		24:00	95.880
	12:00	92.712	3/ 2/82	3:00	95.960
	15:00	92.750		6:00	96.040
	18:00	92.846		9:00	96.193
	21:00	92.790		12:00	96.193
	24:00	92.850		15:00	96.200
2/24/82	3:00	92.920		18:00	96.210
	6:00	93.080		21:00	96.340
	9:00	93.120		24:00	96.400
	12:00	93.195	3/ 3/82	3:00	96.460
	15:00	93.200		6:00	96.650
	18:00	93.280		9:00	96.670
	21:00	93.120		12:00	96.843
	24:00	93.170		15:00	96.820

Readings Extracted from Gravity-Time Curve at 3 Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
3/ 3/82	18:00	96.720	3/10/82	9:00	100.220
	21:00	96.840		12:00	100.257
	24:00	96.900		15:00	100.210
3/ 4/82	3:00	96.970		18:00	100.370
	6:00	97.100		21:00	100.420
	9:00	97.250		24:00	100.480
	12:00	97.212	3/11/82	3:00	100.540
	15:00	97.240		6:00	100.580
	18:00	97.300		9:00	100.660
	21:00	97.240		12:00	100.683
	24:00	97.420		15:00	100.680
3/ 5/82	3:00	97.480		18:00	100.800
	6:00	97.620		21:00	100.900
	9:00	97.610		24:00	100.960
	12:00	97.741	3/12/82	3:00	101.020
	15:00	97.750		6:00	101.080
	18:00	97.780		9:00	101.150
	21:00	97.840		12:00	101.215
	24:00	97.930		15:00	101.200
3/ 6/82	3:00	97.980		18:00	101.280
	6:00	98.050		21:00	101.470
	9:00	98.130		24:00	101.430
	12:00	98.255	3/13/82	3:00	101.480
	15:00	98.330		6:00	101.560
	18:00	98.320		9:00	101.640
	21:00	98.220		12:00	101.598
	24:00	98.440		15:00	101.610
3/ 7/82	3:00	98.510		18:00	101.860
	6:00	98.570		21:00	101.870
	9:00	98.60		24:00	101.930
	12:00	98.730	3/14/82	3:00	101.970
	15:00	98.800		6:00	102.040
	18:00	98.870		9:00	102.100
	21:00	98.750		12:00	102.170
	24:00	98.960		15:00	102.220
3/ 8/82	3:00	99.030		18:00	102.270
	6:00	99.170		21:00	102.340
	9:00	99.170		24:00	102.400
	12:00	99.143	3/15/82	3:00	102.450
	15:00	99.260		6:00	102.588
	18:00	99.330		9:00	102.740
	21:00	99.420		12:00	102.702
	24:00	99.470		15:00	102.760
3/ 9/82	3:00	99.560		18:00	102.840
	6:00	99.600		21:00	102.820
	9:00	99.760		24:00	102.870
	12:00	99.600	3/16/82	3:00	102.940
	15:00	99.780		6:00	103.200
	18:00	99.960		9:00	102.970
	21:00	99.990		12:00	103.200
	24:00	100.010		15:00	103.340
3/10/82	3:00	100.070		18:00	103.360
	6:00	100.220		21:00	103.32

Readings Extracted from Gravity-Time Curve at 3 Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
3/16/82	24:00	103.380	3/23/82	15:00	106.660
3/17/82	3:00	103.440		18:00	106.814
	6:00	103.550		21:00	106.700
	9:00	103.580		24:00	106.760
	12:00	103.723	3/24/82	3:00	106.830
	15:00	103.640		6:00	106.870
	18:00	103.640		9:00	107.060
	21:00	103.800		12:00	107.012
	24:00	103.860		15:00	107.140
3/18/82	3:00	103.920		18:00	107.220
	6:00	103.970		21:00	107.240
	9:00	104.070		24:00	107.250
	12:00	104.169	3/25/82	3:00	107.320
	15:00	104.120		6:00	107.370
	18:00	104.120		9:00	107.570
	21:00	104.270		12:00	107.700
	24:00	104.350		15:00	107.570
3/19/82	3:00	104.400		18:00	107.700
	6:00	104.480		21:00	107.809
	9:00	104.570		24:00	107.720
	12:00	104.687	3/26/82	3:00	107.780
	15:00	104.660		6:00	107.840
	18:00	104.652		9:00	108.010
	21:00	104.610		12:00	107.895
	24:00	104.830		15:00	108.269
3/20/82	3:00	104.860		18:00	108.130
	6:00	104.930		21:00	108.050
	9:00	105.020		24:00	108.180
	12:00	104.998	3/27/82	3:00	108.240
	15:00	105.170		6:00	108.300
	18:00	105.224		9:00	108.620
	21:00	105.130		12:00	108.480
	24:00	105.290		15:00	108.580
3/21/82	3:00	105.360		18:00	108.680
	6:00	105.402		21:00	108.800
	9:00	105.720		24:00	108.670
	12:00	105.545	3/28/82	3:00	108.750
	15:00	105.580		6:00	108.800
	18:00	105.613		9:00	108.850
	21:00	105.720		12:00	109.108
	24:00	105.760		15:00	109.000
3/22/82	3:00	105.830		18:00	109.100
	6:00	105.880		21:00	109.120
	9:00	106.020		24:00	109.180
	12:00	105.990	3/29/82	3:00	109.230
	15:00	106.160		6:00	109.360
	18:00	106.274		9:00	109.520
	21:00	106.200		12:00	109.440
	24:00	106.240		15:00	109.400
3/23/82	3:00	106.320		18:00	109.530
	6:00	106.594		21:00	109.600
	9:00	106.550		24:00	109.640
	12:00	106.492	3/30/82	3:00	109.680

Readings Extracted from Gravity-Time Curve at 3 Hour Intervals

Date	Time (universal)	Reading (mgals)
3/30/82	6:00	109.800
	9:00	109.940
	12:00	109.920
	15:00	109.900
	18:00	109.980
	21:00	110.050
	24:00	110.100
3/31/82	3:00	110.160
	6:00	110.220
	9:00	110.260
	12:00	110.270
	15:00	110.185
	18:00	110.240
	21:00	110.190
	24:00	110.600

Readings Harmonically Analyzed in 12 Hour Periods with Each Reading Spaced at 3 Hour Intervals

A=Readings analyzed from midnight to noon
B=Readings analyzed from noon to midnight

Date	Zeroeth Harmonic (Time Average)	First Harmonic (Fundamental)
2/18/82 B	90.189(mgals)	0.082(mgals)
2/19/82 A	90.436	0.130
2/19/82 B	90.692	0.089
2/20/82 A	90.936	0.107
2/20/82 B	91.208	0.098
2/21/82 A	91.450	0.083
2/21/82 B	91.738	0.109
2/22/82 A	92.014	0.151
2/22/82 B	92.272	0.097
2/23/82 A	92.550	0.165
2/23/82 B	92.790	0.053
2/24/82 A	93.033	0.159
2/24/82 B	93.193	0.049
2/25/82 A	93.506	0.252
2/25/82 B	93.792	0.113
2/26/82 A	94.049	0.165
2/26/82 B	94.271	0.137
2/27/82 A	94.542	0.148
2/27/82 B	94.707	0.172
2/28/82 A	95.027	0.147
2/28/82 B	95.257	0.112
3/ 1/82 A	95.552	0.162
3/ 1/82 B	95.796	0.071
3/ 2/82 A	96.053	0.163
3/ 2/82 B	96.269	0.110
3/ 3/82 A	96.605	0.184
3/ 3/82 B	96.825	0.074
3/ 4/82 A	97.086	0.183
3/ 4/82 B	97.262	0.039
3/ 5/82 A	97.574	0.125
3/ 5/82 B	97.808	0.085
3/ 6/82 A	98.069	0.136
3/ 6/82 B	98.313	0.029
3/ 7/82 A	98.570	0.103
3/ 7/82 B	98.822	0.036
3/ 8/82 A	99.105	0.116
3/ 8/82 B	99.334	0.126
3/ 9/82 A	99.598	0.121
3/ 9/82 B	99.868	0.194
3/10/82 A	100.155	0.121
3/10/82 B	100.347	0.133
3/11/82 A	100.589	0.094
3/11/82 B	100.804	0.150
3/12/82 A	101.085	0.110
3/12/82 B	101.319	0.154
3/13/82 A	101.542	0.105
3/13/82 B	101.774	0.180
3/14/82 A	102.042	0.106
3/14/82 B	102.280	0.100
3/15/82 A	102.576	0.183
3/15/82 B	102.798	0.066
3/16/82 A	103.036	0.100
3/16/82 B	103.320	0.051

Readings Harmonically Analyzed in 12 Hour Periods with Each Reading Spaced at 3 Hour Intervals

A=Readings analyzed from midnight to noon
B=Readings analyzed from noon to midnight

Date	Zeroeth Harmonic (Time Average)	First Harmonic (Fundamental)
3/17/82 A	103.535(mgals)	0.134(mgals)
3/17/82 B	103.732	0.122
3/18/82 A	103.998	0.132
3/18/82 B	104.206	0.123
3/19/82 A	104.497	0.146
3/19/82 B	104.688	0.075
3/20/82 A	104.928	0.101
3/20/82 B	105.162	0.063
3/21/82 A	105.409	0.095
3/21/82 B	105.644	0.105
3/22/82 A	105.896	0.127
3/22/82 B	106.173	0.109
3/23/82 A	106.439	0.182
3/23/82 B	106.685	0.118
3/24/82 A	106.906	0.147
3/24/82 B	107.172	0.107
3/25/82 A	107.408	0.161
3/25/82 B	107.665	0.144
3/26/82 A	107.849	0.133
3/26/82 B	108.083	0.167
3/27/82 A	108.364	0.216
3/27/82 B	108.642	0.147
3/28/82 A	108.836	0.152
3/28/82 B	109.102	0.073
3/29/82 A	109.346	0.175
3/29/82 B	109.522	0.124
3/30/82 A	109.796	0.166
3/30/82 B	109.990	0.102
3/31/82 A	110.202	0.081
3/31/82 B	110.297	0.160

Readings Harmonically Analyzed at 3 hour Intervals in 12 hour Periods Between 6:00 and 18:00

Date	Zeroeth Harmonic (Time Average)	First Harmonic (Fundamental) (12 hr. component)
2/19/82	90.568(mgals)	0.112(mgals)
2/20/82	91.074	0.130
2/21/82	91.600	0.166
2/22/82	92.182	0.122
2/23/82	92.716	0.103
2/24/82	93.175	0.078
2/25/82	93.712	0.084
2/26/82	94.167	0.036
2/27/82	94.613	0.036
2/28/82	95.137	0.090
3/ 1/82	95.692	0.099
3/ 2/82	96.168	0.062
3/ 3/82	96.741	0.107
3/ 4/82	97.220	0.046
3/ 5/82	97.700	0.092
3/ 6/82	98.217	0.145
3/ 7/82	98.714	0.147
3/ 8/82	99.225	0.078
3/ 9/82	99.740	0.119
3/10/82	100.255	0.047
3/11/82	100.680	0.060
3/12/82	101.185	0.067
3/13/82	101.653	0.088
3/14/82	102.160	0.100
3/15/82	102.726	0.067
3/16/82	103.214	0.189
3/17/82	103.626	0.070
3/18/82	104.090	0.082
3/19/82	104.610	0.096
3/20/82	105.068	0.129
3/21/82	105.518	0.101
3/22/82	106.065	0.149
3/23/82	106.622	0.144
3/24/82	107.060	0.113
3/25/82	107.548	0.078
3/26/82	107.991	0.112
3/27/82	108.532	0.078
3/28/82	108.972	0.140
3/29/82	109.450	0.006
3/30/82	109.908	0.033
3/31/82	110.235	0.028

Readings Harmonically Analyzed in 24 Hour Periods with Each Reading Spaced at 3 Hour Intervals

-Readings grouped from noon to noon-

Dates	Zeroeth Harmonic (Time Average) (mgals)	First Harmonic (24 hr.) (mgals)	Second Harmonic (12 hr.) (mgals)
2/18/82 - 2/19/82	90.316	0.173	0.098
19 - 20	90.814	0.185	0.083
20 - 21	91.327	0.174	0.080
21 - 22	91.880	0.202	0.125
22 - 23	92.417	0.202	0.124
23 - 24	92.918	0.185	0.098
24 - 25	93.369	0.268	0.112
25 - 26	93.925	0.183	0.139
26 - 27	94.407	0.212	0.132
27 - 28	94.865	0.238	0.148
2/28/82 - 3/ 1/82	95.407	0.234	0.117
1 - 2	95.929	0.207	0.100
2 - 3	96.440	0.259	0.125
3 - 4	96.960	0.228	0.079
4 - 5	97.417	0.238	0.049
5 - 6	97.939	0.195	0.099
6 - 7	98.440	0.192	0.038
7 - 8	98.963	0.214	0.064
8 - 9	99.465	0.208	0.108
9 - 10	100.011	0.209	0.153
10 - 11	100.466	0.183	0.106
11 - 12	100.942	0.210	0.120
12 - 13	101.430	0.178	0.116
13 - 14	101.904	0.194	0.141
14 - 15	102.430	0.228	0.129
15 - 16	102.922	0.175	0.067
16 - 17	103.432	0.152	0.083
17 - 18	103.865	0.210	0.109
18 - 19	104.351	0.227	0.115
19 - 20	104.804	0.194	0.039
20 - 21	105.284	0.168	0.072
21 - 22	105.770	0.193	0.104
22 - 23	106.312	0.200	0.142
23 - 24	106.799	0.148	0.132
24 - 25	107.294	0.168	0.132
25 - 26	107.760	0.140	0.137
26 - 27	108.227	0.198	0.129
27 - 28	108.746	0.121	0.144
28 - 29	109.228	0.205	0.104
29 - 30	109.660	0.212	0.135
30 - 31	110.095	0.164	0.077
3/31/82 - 4/ 1/82	110.480	0.304	0.075

Readings Harmonically Analyzed in 48 Hour Periods with Each Reading Spaced at 3 Hour Intervals

-Readings grouped from midnight to midnight-

Dates	Zeroeth Harmonic (Time Average) (mgals)	Second Harmonic (24 hr.) (mgals)	Fourth Harmonic (12 hr.) (mgals)
2/19/82 - 2/21/82	90.813	0.182	0.088
21 - 23	91.871	0.193	0.086
23 - 25	92.886	0.154	0.079
25 - 27	93.907	0.181	0.161
2/27/82 - 3/ 1/82	94.878	0.124	0.140
1 - 3	95.910	0.158	0.114
3 - 5	96.942	0.147	0.096
5 - 7	97.933	0.161	0.078
7 - 9	98.955	0.165	0.075
9 - 11	99.997	0.158	0.133
11 - 13	100.947	0.154	0.118
13 - 15	101.910	0.161	0.117
15 - 17	102.932	0.182	0.074
17 - 19	103.857	0.129	0.115
19 - 21	104.813	0.151	0.055
21 - 23	105.782	0.181	0.076
23 - 25	106.807	0.185	0.128
25 - 27	107.756	0.186	0.125
27 - 29	108.731	0.205	0.134
29 - 31	109.661	0.123	0.138

Readings Harmonically Analyzed in 48 Hour Periods with Each Reading Spaced at 3 Hour Intervals

-Readings grouped from noon to noon-

Dates	Zeroeth Harmonic (Time Average) (mgals)	Second Harmonic (24 hr.) (mgals)	Fourth Harmonic (12 hr.) (mgals)
2/18/82 - 2/20/82	90.560	0.167	0.090
20 - 22	91.604	0.179	0.088
22 - 24	92.664	0.185	0.111
24 - 26	93.647	0.210	0.121
26 - 28	94.638	0.213	0.146
2/28/82 - 3/ 2/82	95.661	0.210	0.103
2 - 4	96.691	0.234	0.104
4 - 6	97.673	0.206	0.074
6 - 8	98.699	0.193	0.038
8 - 10	99.745	0.193	0.118
10 - 12	100.704	0.186	0.111
12 - 14	101.671	0.174	0.123
14 - 16	102.674	0.191	0.086
16 - 18	103.643	0.168	0.097
18 - 20	104.570	0.204	0.076
20 - 22	105.525	0.170	0.087
22 - 24	106.558	0.165	0.133
24 - 26	107.526	0.138	0.129
26 - 28	108.486	0.144	0.165
28 - 30	109.444	0.197	0.122
3/30/82 - 4/ 1/82	110.287	0.229	0.085

Readings Harmonically Analyzed in Weekly Periods with Each Reading Spaced at 3 Hour Intervals

-Readings grouped from noon to noon-

Dates	Seventh Harmonic (24 hr.) (mgals)	Fourteenth Harmonic (12 hr.) (mgals)
2/18/82 - 2/25/82	0.186	0.082
2/25/82 - 3/ 4/82	0.206	0.122
3/ 4/82 - 3/11/82	0.180	0.075
3/11/82 - 3/18/82	0.178	0.102
3/18/82 - 3/25/82	0.171	0.076
3/25/82 - 4/ 1/82	0.171	0.126

-Readings grouped from midnight to midnight-

Dates	Seventh Harmonic (24 hr.) (mgals)	Fourteenth Harmonic (12 hr.) (mgals)
2/19/82 - 2/26/82	0.165	0.081
2/26/82 - 3/ 5/82	0.128	0.116
3/ 5/82 - 3/12/82	0.156	0.087
3/12/82 - 3/19/82	0.145	0.103
3/19/82 - 3/26/82	0.169	0.086

Readings Extracted from Gravity-Time Curve at 2½ Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
2/18/82	12:00	90.050	2/24/82	0:30	92.860
	14:30	90.160		3:00	92.920
	17:00	90.230		5:30	93.080
	19:30	90.200		8:00	93.095
	22:00	90.240		10:30	93.150
2/19/82	0:30	90.290		13:00	93.200
	3:00	90.350		15:30	93.200
	5:30	90.471		18:00	93.270
	8:00	90.440		20:30	93.420
	10:30	90.540		23:00	93.360
	13:00	90.670	2/25/82	1:30	93.420
	15:30	90.643		4:00	93.460
	18:00	90.610		6:30	93.600
	20:30	90.700		9:00	93.730
	23:00	90.780		11:30	93.630
2/20/82	1:30	90.830		14:00	93.733
	4:00	90.870		16:30	93.740
	6:30	90.950		19:00	93.920
	9:00	91.020		21:30	93.840
	11:30	91.060		24:00	93.880
	14:00	91.120	2/26/82	2:30	93.920
	16:30	91.250		5:00	94.000
	19:00	91.230		7:30	94.170
	21:30	91.260		10:00	94.210
	24:00	91.330		12:30	94.140
2/21/82	2:30	91.390		15:00	94.180
	5:00	91.440		17:30	94.260
	7:30	91.500		20:00	94.360
	10:00	91.560		22:30	94.370
	12:30	91.620	2/27/82	1:00	94.430
	15:00	91.650		3:30	94.470
	17:30	91.710		6:00	94.520
	20:00	91.848		8:30	94.580
	22:30	91.830		11:00	94.620
2/22/82	1:00	91.850		13:30	94.560
	3:30	91.920		16:00	94.641
	6:00	92.030		18:30	94.650
	8:30	92.140		21:00	94.830
	11:00	92.130		23:30	94.850
	13:30	92.160	2/28/82	2:00	94.920
	16:00	92.354		4:30	94.970
	18:30	92.370		7:00	95.040
	21:00	92.280		9:30	95.080
	23:30	92.330		12:00	95.244
2/23/82	2:00	92.380		14:30	95.130
	4:30	92.440		17:00	95.170
	7:00	92.630		19:30	95.260
	9:30	92.630		22:00	95.340
	12:00	92.710	3/ 1/82	0:30	95.390
	14:30	92.740		3:00	95.430
	17:00	92.810		5:30	95.576
	19:30	92.840		8:00	95.581
	22:00	92.820		10:30	95.600

Readings Extracted from Gravity-Time Curve at 2½ Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
3/ 1/82	13:00	95.780	3/ 7/82	1:30	98.480
	15:30	95.700		4:00	98.520
	18:00	95.720		6:30	98.560
	20:30	95.800		9:00	98.600
	23:00	95.870		11:30	98.700
3/ 2/82	1:30	95.930		14:00	98.733
	4:00	95.970		16:30	98.715
	6:30	96.040		19:00	98.630
	9:00	96.193		21:30	98.700
	11:30	96.200	3/ 8/82	2:30	98.840
	14:00	96.200		5:00	99.165
	16:30	96.200		7:30	99.160
	19:00	96.220		10:00	99.160
	21:30	96.360		12:30	99.210
	24:00	96.400		15:00	99.270
3/ 3/82	2:30	96.440		17:30	99.310
	5:00	96.657		20:00	99.402
	7:30	96.630		22:30	99.440
	10:00	96.700	3/ 9/82	1:00	99.520
	12:30	96.840		3:30	99.570
	15:00	96.800		6:00	99.600
	17:30	96.730		8:30	99.740
	20:00	96.826		11:00	99.640
	22:30	96.870		13:30	99.660
3/ 4/82	1:00	96.920		16:00	99.877
	3:30	96.960		18:30	99.950
	6:00	97.100		21:00	99.970
	8:30	97.240		23:30	100.030
	11:00	97.240	3/10/82	2:00	100.040
	13:30	97.200		4:30	100.110
	16:00	97.332		7:00	100.220
	18:30	97.240		9:30	100.220
	21:00	97.340		12:00	100.257
	23:30	97.420		14:30	100.208
3/ 5/82	2:00	97.460		17:00	100.340
	4:30	97.520		19:30	100.390
	7:00	97.600		22:00	100.440
	9:30	97.630	3/11/82	0.30	100.480
	12:00	97.741		3:00	100.530
	14:30	97.740		5:30	100.589
	17:00	97.770		8:00	100.629
	19:30	97.823		10:30	100.680
	22:00	97.870		13:00	100.700
3/ 6/82	0:30	97.940		15:30	100.700
	3:00	97.980		18:00	100.800
	5:30	98.040		20:30	100.930
	8:00	98.124		23:00	100.930
	10:30	98.200	3/12/82	1:30	100.980
	13:00	98.260		4:00	101.040
	15:30	98.320		6:30	101.120
	18:00	98.270		9:00	101.130
	20:30	98.200		11:30	101.200
	23:00	98.420		14:00	101.220

Readings Extracted from Gravity-Time Curve at 2½ Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
3/12/82	16:30	101.240	3/18/82	7:30	104.000
	19:00	101.300		10:00	104.100
	21:30	101.520		12:30	104.160
	24:00	101.430		15:00	104.130
3/13/82	2:30	101.280		17:30	104.110
	5:00	101.500		20:00	104.223
	7:30	101.630		22:30	104.330
	10:00	101.640	3/19/82	1:00	104.380
	12:30	101.580		3:30	104.400
	15:00	101.630		6:00	104.460
	17:30	101.820		8:30	104.520
	20:00	101.930		11:00	104.640
	22:30	101.900		13:30	104.670
3/14/82	1:00	101.940		16:00	104.707
	3:30	101.970		10:30	104.630
	6:00	102.040		21:00	104.630
	8:30	102.080		23:30	104.780
	11:00	102.160	3/20/82	12:00	104.830
	13:30	102.180		4:30	104.810
	16:00	102.220		7:00	104.940
	18:30	102.280		9:30	105.020
	23:30	102.380		12:00	104.998
3/15/82	2:00	102.440		14:30	105.180
	4:30	102.500		17:00	105.200
	7:00	102.650		19:30	105.170
	9:30	102.720		22:00	105.161
	12:00	102.702	3/21/82	0:30	105.320
	14:30	102.730		3:00	105.370
	17:00	102.820		5:30	105.380
	19:30	102.840		8:00	105.487
	22:00	102.840		10:30	105.470
3/16/82	0:30	102.900		13:00	105.530
	4:00	102.970		15:30	105.600
	6:30	103.200		18:00	105.613
	8:00	103.183		20:30	105.700
	10:30	103.190		23:00	105.760
	13:00	103.220	3/22/82	1:30	105.800
	15:30	103.360		4:00	105.840
	18:00	103.360		6:30	105.900
	20:30	103.270		9:00	106.020
	23:00	103.340		11:30	106.020
3/17/82	1:30	103.410		14:00	106.157
	4:00	103.440		16:30	106.220
	6:30	103.520		19:00	106.250
	9:00	103.580		21:30	106.200
	11:30	103.700		24:00	106.270
	14:00	103.680	3/23/82	2:30	106.320
	16:30	103.600		5:00	106.360
	19:00	103.740		7:30	106.500
	21:30	103.840		10:00	106.560
	24:00	103.860		12:30	106.550
3/18/82	2:30	103.920		15:00	106.680
	5:00	103.960		17:30	106.760

Readings Extracted from Gravity-Time Curve at 2½ Hour Intervals

Date	Time (universal)	Reading (mgals)	Date	Time (universal)	Reading (mgals)
3/23/82	20:00	106.706	3/28/82	7:30	108.830
	22:30	106.740		10:00	108.860
3/24/82	1:00	106.770		12:30	109.100
	3:30	106.830		15:00	109.020
	6:00	106.870		17:30	109.080
	8:30	107.060		20:00	109.254
	11:00	107.000		22:30	109.160
	13:30	107.040	3/29/82	1:00	109.200
	16:00	107.213		3:30	109.230
	18:30	107.260		6:00	109.330
	21:00	107.280		8:30	109.500
	23:30	107.240		11:00	109.520
3/25/82	2:00	107.280		13:30	109.420
	4:30	107.330		16:00	109.478
	7:00	107.400		18:30	109.560
	9:30	107.560		21:00	109.580
	12:00	107.529		23:30	109.620
	14:30	107.570	3/30/82	2:00	109.680
	17:00	107.550		4:30	109.700
	19:30	107.780		7:00	109.840
	22:00	107.820		9:30	109.920
3/26/82	0:30	107.760		12:00	109.900
	3:00	107.780		14:30	109.920
	5:30	107.830		17:00	109.934
	8:00	107.982		19:30	110.000
	10:30	107.980		22:00	110.060
	13:00	107.920	3/31/82	0:30	110.013
	15:30	107.960		3:00	110.013
	18:00	108.269		5:30	110.152
	20:30	108.240		8:00	110.230
	23:00	108.170		10:30	110.300
3/27/82	1:30	108.220		13:00	110.250
	4:00	108.260		15:30	110.190
	6:30	108.330		18:00	110.230
	9:00	108.620		20:30	110.200
	11:30	108.480		23:00	110.570
	14:00	108.520	4/ 1/82	1:30	110.610
	16:30	108.630		4:00	110.640
	19:00	108.770		6:30	110.700
	21:30	108.683		9:00	110.740
	24:00	108.680		11:30	110.800
3/28/82	2:30	108.730		14:00	110.840
	5:00	108.780		16:30	110.930

Readings Harmonically Analyzed in 12.50 Hour Periods with Each Reading Spaced at 2½ Hour Intervals

Six readings in a period
Harmonics Tabulated Chronologically

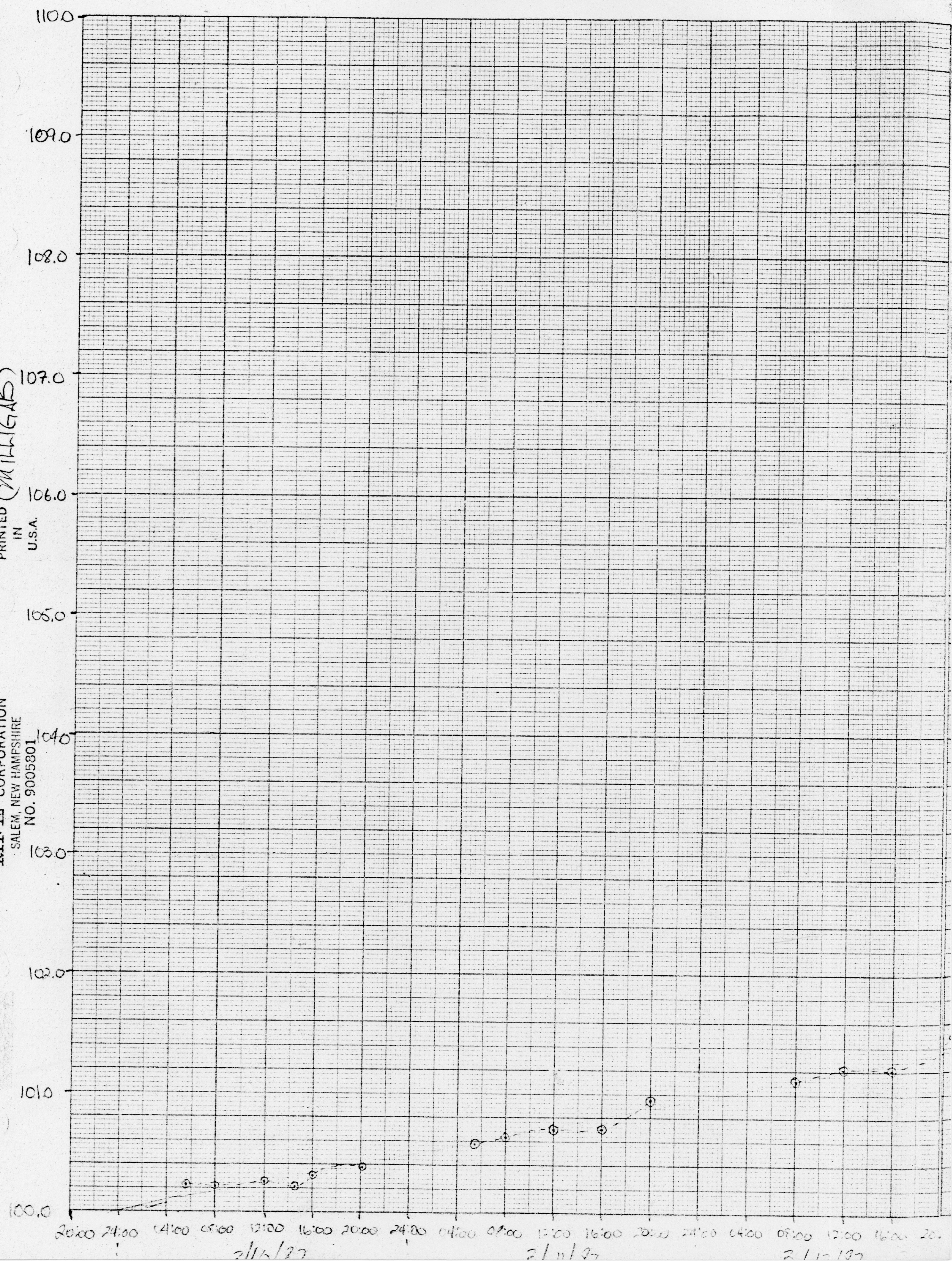
	First Harmonic (12.50 hr.) (mgals)		First Harmonic (12.50 hr.) (mgals)
1	0.034	42	0.054
2	0.061	43	0.058
3	0.052	44	0.083
4	0.062	45	0.097
5	0.038	46	0.051
6	0.057	47	0.051
7	0.047	48	0.087
8	0.057	49	0.037
9	0.030	50	0.073
10	0.056	51	0.005
11	0.050	52	0.071
12	0.038	53	0.072
13	0.041	54	0.060
14	0.043	55	0.077
15	0.066	56	0.069
16	0.041	57	0.070
17	0.047	58	0.064
18	0.044	59	0.063
19	0.057	60	0.043
20	0.033	61	0.079
21	0.066	62	0.074
22	0.028	63	0.057
23	0.078	64	0.061
24	0.052	65	0.061
25	0.078	66	0.077
26	0.183	67	0.064
27	0.088	68	0.074
28	0.046	69	0.061
29	0.053	70	0.096
30	0.052	71	0.099
31	0.081	72	0.065
32	0.077	73	0.066
33	0.054	74	0.046
34	0.099	75	0.086
35	0.038	76	0.047
36	0.059	77	0.064
37	0.065	78	0.055
38	0.049	79	0.041
39	0.037	80	0.132
40	0.049	81	0.053
41	0.051		

Degree of Linearity of Gravity-Time Curve

	Linear Correlation Coefficient (1 = perfect linearity)	Variability
	0.85786	0.00136
	0.76461	0.00113
	0.89025	0.00020
	0.92832	0.00009
	0.94675	0.00005
	0.95764	0.00003
	0.96483	0.00002
	0.96994	0.00002
	0.97380	0.00001
	0.97669	0.00001
	0.97905	0.00001
	0.98097	0.00001
	0.98257	0.00001
	0.98391	0.00000
	0.98508	0.00000
	0.98607	0.00000
	0.98694	0.00000
	0.98771	0.00000
	0.98839	0.00000
	0.98901	0.00000
	0.98956	0.00000
	0.99006	0.00000
	0.99051	0.00000
	0.99092	0.00000
	0.99129	0.00000
	0.99165	0.00000
	0.99197	0.00000
	0.99226	0.00000
	0.99254	0.00000
	0.99279	0.00000
	0.99304	0.00000
	0.99326	0.00000
	0.99346	0.00000
	0.99366	0.00000
	0.99385	0.00000
	0.99403	0.00000
	0.99418	0.00000
	0.99434	0.00000
	0.99449	0.00000
	0.99463	0.00000
	0.99476	0.00000
	0.99486	0.00000
Average	0.97680	0.00007

```
C     PROGRAM TO CALCULATE DEGREE OF LINEARITY OF GRAVITY-TIME CURVE
C     X=TIME
C     Y=GRAVITY
C     SQX=X SQUARED
C     SQY=Y SQUARED
C     SUMXY=SUM OF ALL X'S AND Y'S
C     SLOPE=SLOPE OF LINE
C     CORR=CORRELATION COEFFICIENT
C     VAR=VARIABILITY OF CORRELATION COEFFICIENT
C
      DIMENSION X(372),Y(372),SQX(372),SQY(372),SUMXY(372),DEL(42),
     *SLOPE(42),CORR(42),VAR(42)
C     INITIATE LOOPS TO READ IN DATA
      DO 1 I=1,42
           READ(5,10) X(I),Y(I)
1     CONTINUE
      MO=1
      N=MO+8
      M=9
C     INITIALIZE VARIABLES
      SUMTXY=0
      SUMXSQ=0
      SUMYSQ=0
      SUMX=0
      SUMY=0
C     CALCULATE X SQUARED TERMS, Y SQUARED TERMS, AND SUM X & Y TERMS
      DO 2 I=1,42
           DO 3 J=1,N
                SQX(J)=X(J)**2
                SQY(J)=Y(J)**2
                SUMXY(J)=X(J)+Y(J)
3          CONTINUE
           DO 4 K=1,N
                SUMX=SUMX+X(K)
                SUMY=SUMY+Y(K)
                SUMXSQ=SUMXSQ+SQX(K)
                SUMYSQ=SUMYSQ+SQY(K)
                SUMTXY=SUMTXY+SUMXY(K)
4          CONTINUE
C     CALCULATE SLOPE, CORRELATION COEFFICIENT, AND VARIABILITY COEFF.
      DEL(I)=M*SUMXSQ-SUMX**2
      SLOPE(I)=(M*SUMTXY-SUMX*SUMY)/(M*SUMXSQ-SUMX**2)
      CORR(I)=DEL(I)*(SQRT((M*SUMXSQ-SUMX**2)/(M*SUMYSQ-SUMY**2)))
      VAR(I)=M*CORR(I)**2/DEL(I)
      WRITE(6,20)DEL(I),SLOPE(I),CORR(I),VAR(I)
2     CONTINUE
      DELTA=0
      SLOPES=0
      CORRS=0
      VARS=0
C     SUM SLOPES, CORRELATION COEFFICIENTS, VARIABILITY COEFFICIENTS,
C     AND FIND AVERAGES OF EACH
      DO 5 L=1,42
           DELTA=DELTA+DEL(L)
           SLOPES=SLOPES+SLOPE(L)
           CORRS=CORRS+CORR(L)
           VARS=VARS+VAR(L)
```

```
5     CONTINUE
      AVDEL=DELTA/42
      AVSLO=SLOPES/42
      AVCOR=CORRS/42
      AVVAR=VARS/42
      WRITE(6,30)AVDEL,AVSLO,AVCOR,AVVAR
10    FORMAT(F6.3,5X,F3.1)
20    FORMAT(5X,F8.4,5X,F8.4,5X,F8.4,5X,F8.4)
30    FORMAT(10X,F9.5,5X,F9.5,5X,F9.5,5X,F9.5)
      STOP
      END
```



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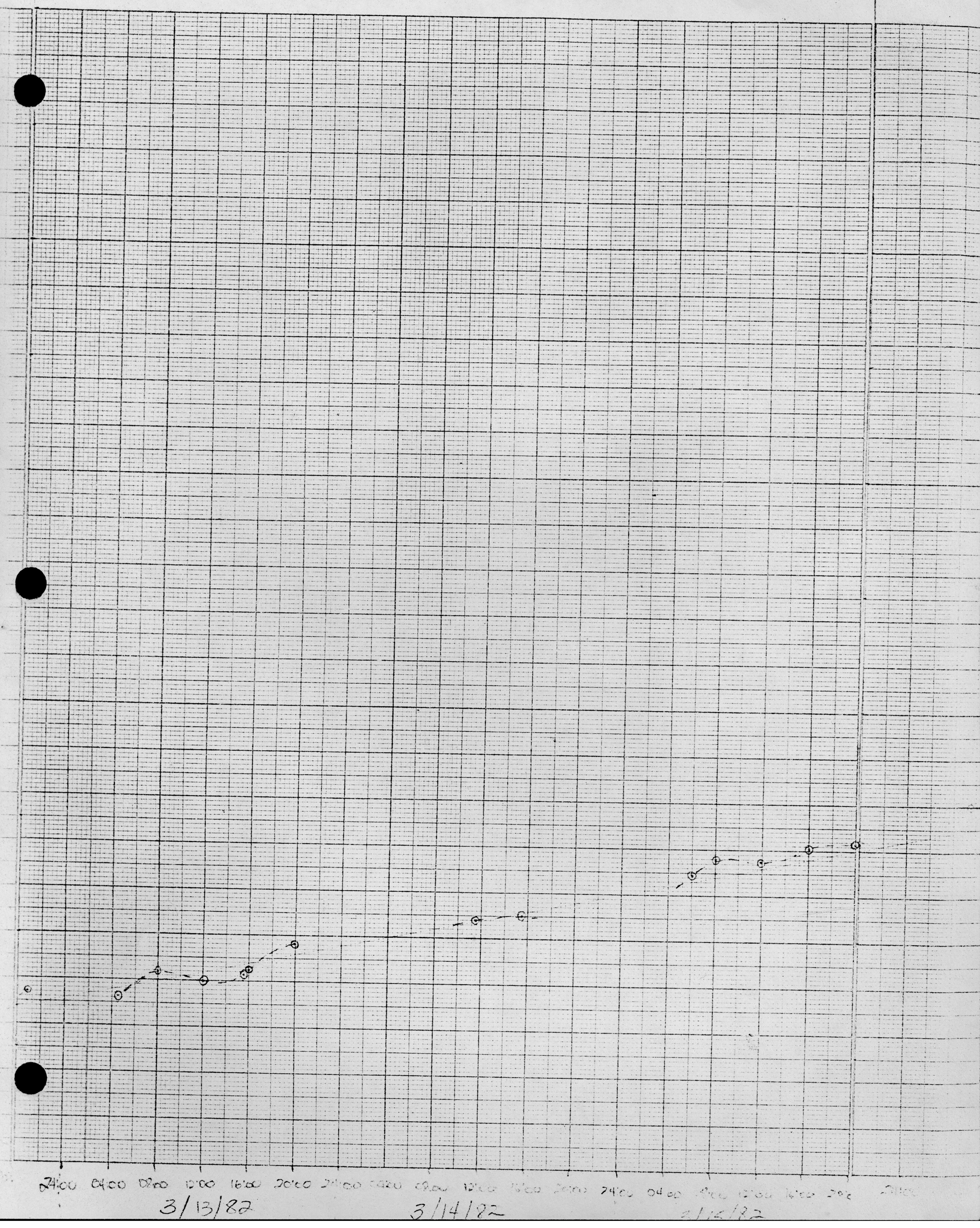
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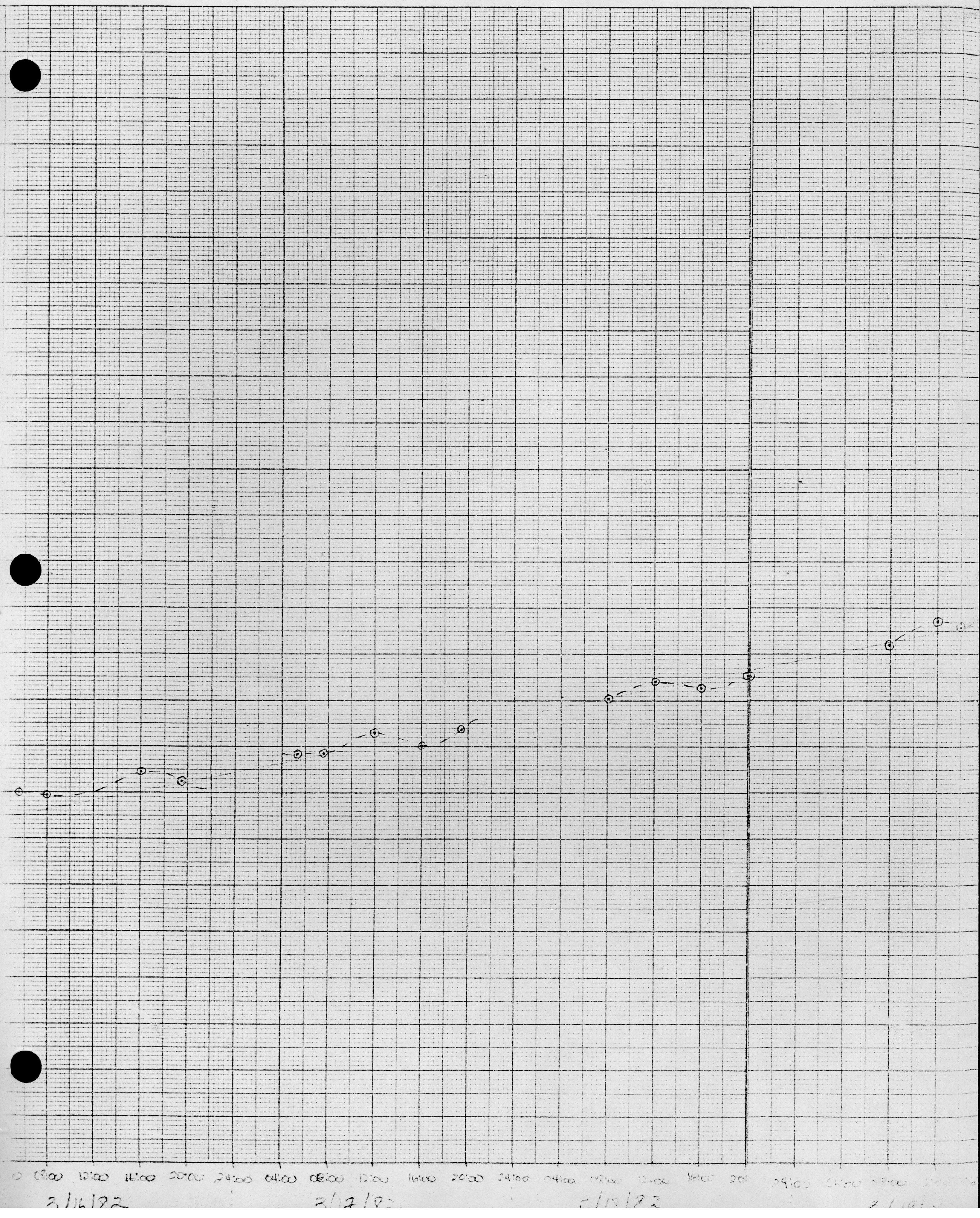
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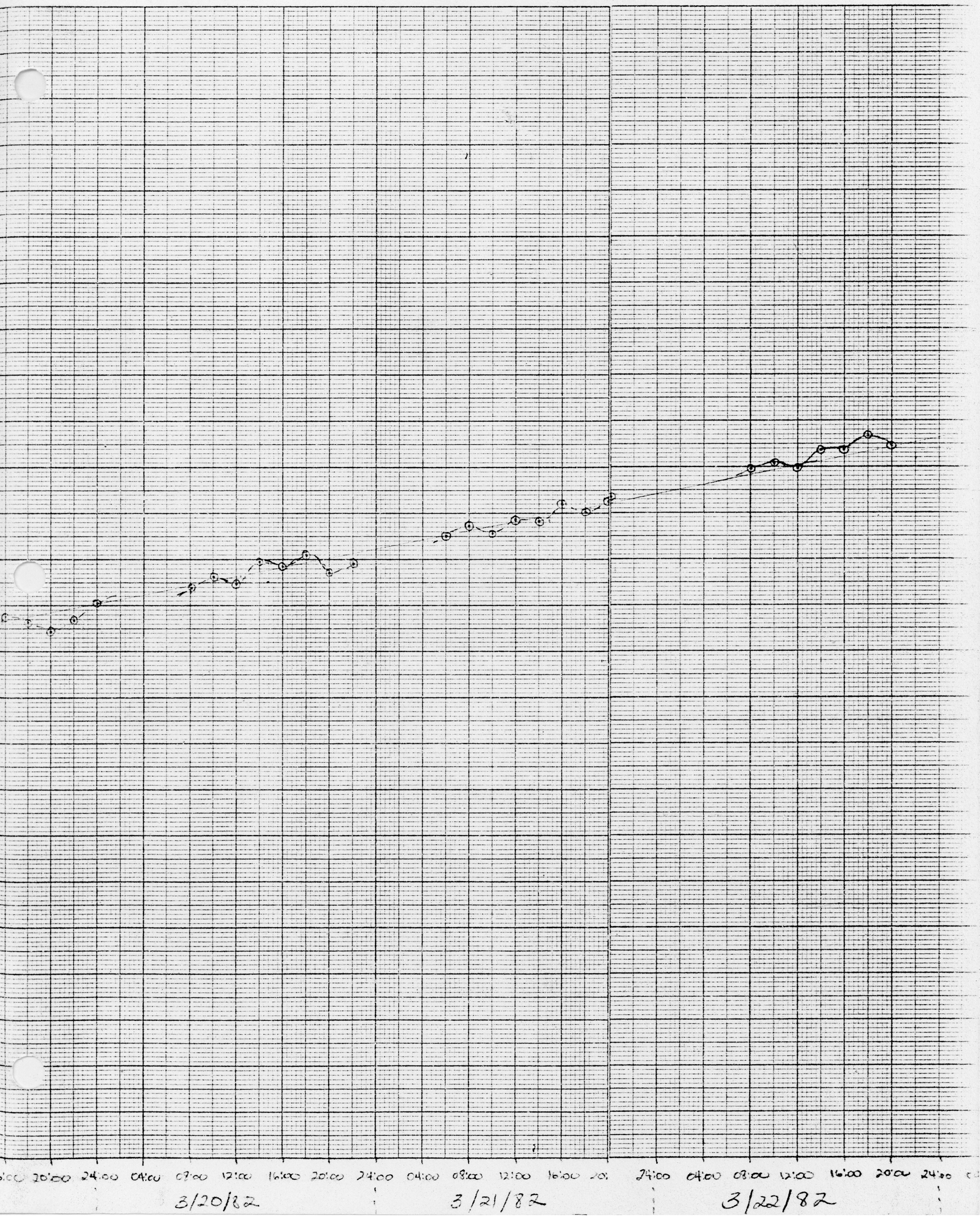
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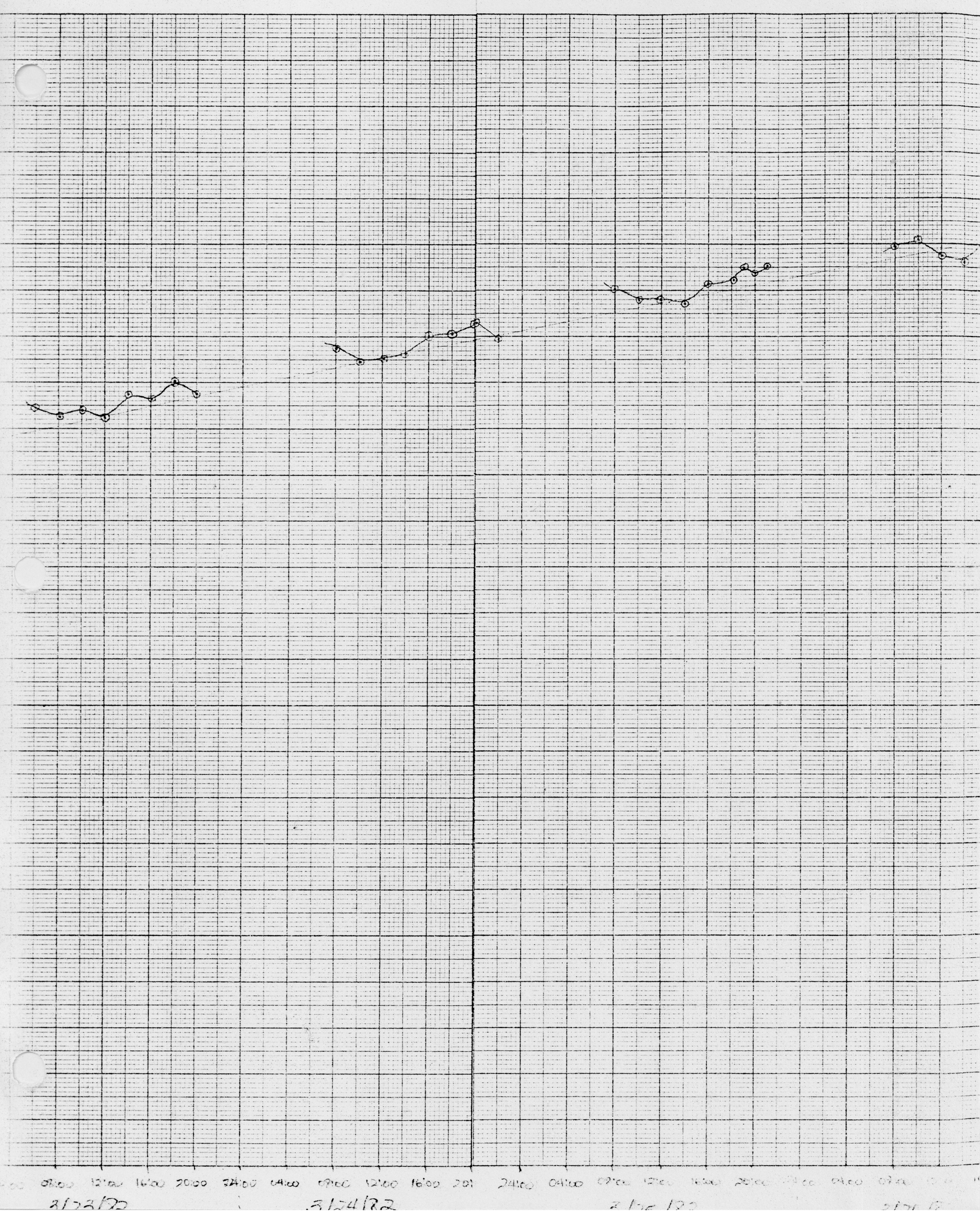
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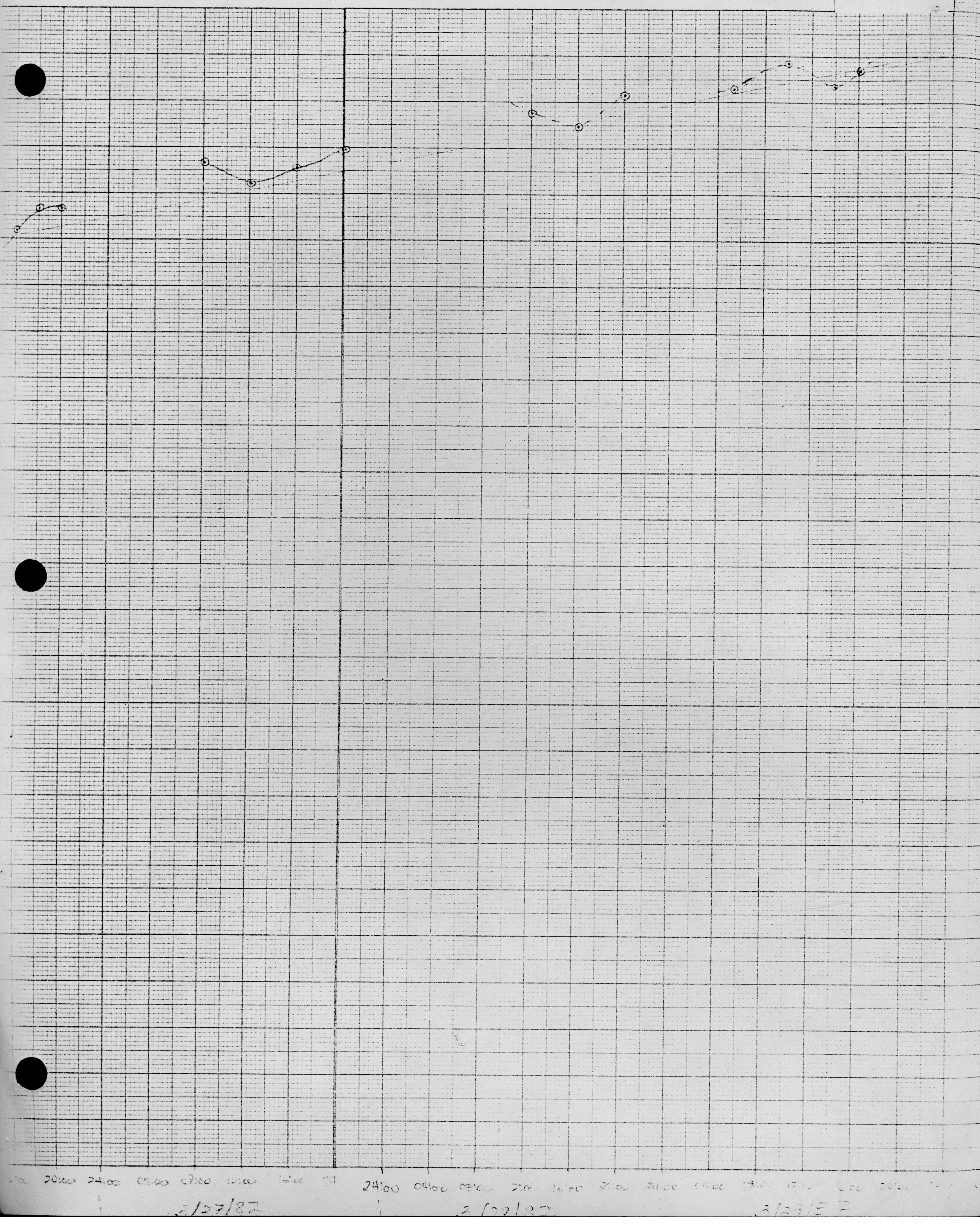

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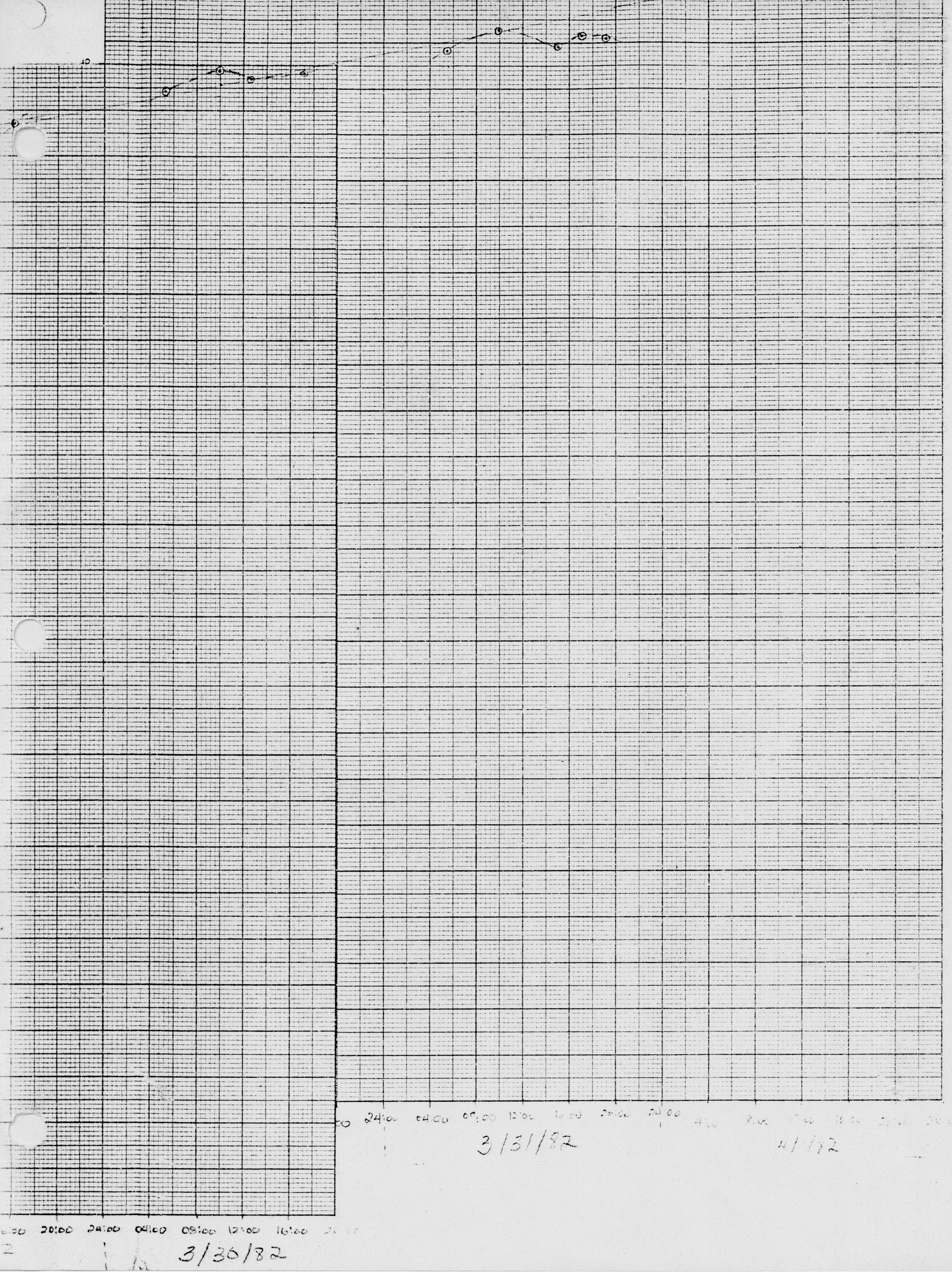
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